(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 1 253 151 A1

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
30.10.2002 Bulletin 2002/44

(21) Application number: 02252947.3

(22) Date of filing: 25.04.2002

(51) Int Cl.[7]: C07F 1/08, C07F 3/00, C07F 3/02, C07F 3/06, C07F 5/02, C07F 11/00, C07F 15/00, C07F 15/02, C07F 15/04, C09K 11/00

(84) Designated Contracting States:
AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU MC NL PT SE TR
Designated Extension States:
AL LT LV MK RO SI

(30) Priority: 25.04.2001 JP 2001127311
28.05.2001 JP 2001158325

(71) Applicant: TORAY INDUSTRIES, INC.
Tokyo 103-8666 (JP)

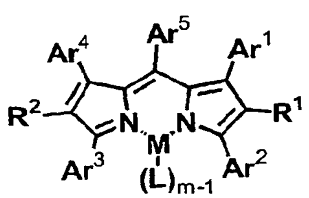
(72) Inventors:
- Murase, Seiichiro, c/o Toray Hokuen-ryo C322
  Otsu-shi, Shiga 520-0842 (JP)
- Tominaga, Tsuyoshi
  Otsu-shi, Shiga 520-2152 (JP)
- Kohama, Akira
  Otsu-shi, Shiga 520-0834 (JP)

(74) Representative: Coleiro, Raymond et al
MEWBURN ELLIS
York House
23 Kingsway
London WC2B 6HP (GB)

(54) **Pyrromethene metal complex and light emitting device composition and light emitting devices using the same**

(57) A pyrromethene metal complex of formula (1) is used as a fluorescent dye to form a light emitting device. The light emitting device includes a material which brings about light emission between an anode and a cathode. By applying electrical energy, the device generates emission having an emission peak wavelength of 580 to 720 nm. The device contains at least one of: a diketopyrrolo[3,4-c]pyrrole derivative and an organic fluorescent material having a fluorescent peak wavelength of 580 to 720 nm; and a light emitting device composition containing a pyrromethene metal complex of formula (1).

Formula (1) is



(1)

wherein each of R^1, R^2 and the or each L, independently of each other, is a group selected from hydrogen, alkyl, cycloalkyl, aralkyl, alkenyl, cycloalkenyl, alkynyl, hydroxyl, mercapto, alkoxy, alkylthio, aryl ether, aryl thioether, aryl, heterocyclic, halogen, haloalkane, haloalkene, haloalkyne, cyano, aldehyde, carbonyl, carboxyl, ester, carbamoyl, amino, nitro, silyl, siloxanyl, and fused aromatic and alicyclic rings each formed with an adjacent group selected from Ar^1 to Ar^4 and M is a metal having a valence of m and is selected from boron, beryllium, magnesium, chromium, iron, nickel, copper, zinc, and platinum; and each of Ar^1 to Ar^5, independently of each other, is an optionally substituted aryl group.

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Description

[0001] The present invention relates to pyrromethene metal complexes for use as fluorescent dye and to light emitting devices (LEDs) using the same.

[0002] Organic thin-film LEDs, from which light is emitted when electrons injected from a cathode are recombined with holes injected from an anode in an organic fluorescent material between the cathode and the anode, have recently been studied with great interest. These devices are of interest because they can be formed in a thin structure, can emit light with high luminance under a low driving voltage, and can emit multicolored light depending on the fluorescent materials used.

[0003] Many research organizations have studied these elements since C. W. Tang et al of Kodak disclosed that an organic thin-film LED emits light with high luminance (Appl. Phys. Lett. 51 (12) 21, p. 913, 1987). A typical organic thin-film LED developed by Kodak comprises a hole transporting diamine compound, 8-hydroxyquinoline aluminium serving as a emissive layer, and a Mg-Ag cathode, in that order, on an ITO glass substrate. This LED was able to emit green light with a luminance of 1000 cd/m^2 under a driving voltage of about 10 V. Some existing organic thin-film LEDs have undergone certain modifications. For example, an electron transporting layer may be additionally disposed in a device.

[0004] Research in green emissive materials is the most advanced for multicolored emission. Red and blue emissive materials are still required to be more durable and to have high luminance and chromatic purity, and have been studied more intensely.

[0005] Examples of red emissive materials include perylenes such as bis(diisopropylphenyl)perylene, perynone, porphyrin, and Eu complexes (Chem. Lett., 1267(1991)).

[0006] In addition, a method has been studied in which a host material is doped with a red fluorescent material to generate red emission. Examples of host materials include quinolinol metal complexes such as tris(8-quinolinolato) aluminum, bis(10-benzoquinolinate)beryllium, diarylbutadienes, stilbenes, and benzothiazoles. These host materials are doped with 4-(dicyanomethylene)-2-methyl-6-(p-dimethylaminostyryl)-4H-pyran, metal phthalocyanine complexes such as MgPc and AlPcCl, squariliums, and violanthrones to generate red luminescence.

[0007] Unfortunately, some of the known emissive materials including host materials and dopants have low luminance efficiency and thus have a high power consumption, and others are not durable and thus result in a short lifetime of the LED. Moreover, concentration quenching and exciplex and excimer formations often lower the fluorescence intensity when the materials are in a thin-film state even though the materials have high fluorescence when they are in a solution. Thus, many of the materials cannot provide high luminance suitable for LEDs. It is a considerable problem that particularly most of the red emissive materials including host materials and dopants cannot provide both high chromatic purity and high luminance, simultaneously.

[0008] In JP-A-2000-208270, a diketopyrrolo[3,4-c]pyrrole derivative and an organic fluorescent material having a peak fluorescent wavelength of 580 to 720 nm are used to generate a red emission, but cannot lead to high luminance.

[0009] Accordingly, the present invention addresses the above-described problem in an attempt to provide a new pyrromethene metal complex capable of resulting in an LED having high luminance efficiency and high chromatic purity and an LED using the same.

[0010] The present invention is directed to a pyrromethene metal complex.

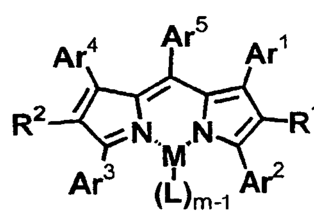
[0011] The present invention is also directed to an LED material comprising the pyrromethene metal complex.

[0012] The present invention is also directed to an LED generating a emission having an emission peak wavelength in the range of 580 to 720 nm by electrical energy. The device comprises at least one of: an LED material comprising a diketopyrrolo[3,4-c]pyrrole derivative and an organic fluorescent material having a fluorescent peak wavelength of 580 to 720 nm; and an LED material comprising a pyrromethene metal complex.

[0013] Since such pyrromethene metal complexes embodying the invention have highly fluorescent properties, they can therefore be used for LEDs. By using such a pyrromethene metal complex, an LED having a high energy efficiency, a high luminance, and a high chromatic purity can be achieved.

[0014] Preferred embodiments of the present invention will now be described.

[0015] A pyrromethene metal complex according to the invention is represented by the chemical formula (1)

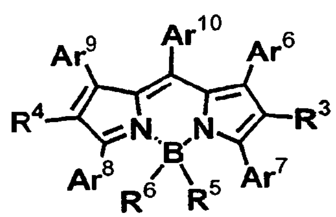


(1)

wherein each of R^1, R^2 and the or each L, independently of each other, is a group selected from hydrogen, alkyl, cycloalkyl, aralkyl, alkenyl, cycloalkenyl, alkynyl, hydroxyl, mercapto, alkoxy, alkylthio, aryl ether, aryl thioether, aryl, heterocyclic, halogen, haloalkane, haloalkene, haloalkyne, cyano, aldehyde, carbonyl, carboxyl, ester, carbamoyl, amino, nitro, silyl, siloxanyl, and fused aromatic and alicyclic rings each formed with an adjacent group selected from Ar^1 to Ar^4 and the or each group L. In particular, when (m-1) 2, two adjacent groups L may together form a fused aromatic or alicyclic ring. M represents a metal having a valence of m and is selected from boron, beryllium, magnesium, chromium, iron, nickel, copper, zinc, and platinum. Each of Ar^1 to Ar^5, independently of one another is an optionally substituted aryl group or any of Ar^1 to Ar^4, together with an adjacent group selected from R^1, R^2 and the or each group L may form a fused aromatic or alicyclic ring.

[0016] In these groups, the alkyl group may be a saturated, preferably C_{1-4}, aliphatic hydrocarbon group such as methyl, ethyl, propyl or butyl. The cycloalkyl group may be a saturated, preferably C_{3-10}, alicyclic ring such as cyclopropyl, cyclohexyl, norbornyl or adamantyl. The aralkyl group may be a group formed with an aromatic hydrocarbon having an aliphatic hydrocarbon therebetween, such as benzyl or phenylethyl. The alkenyl group may be an unsaturated aliphatic hydrocarbon group having a double bond, such as vinyl, allyl or butadienyl. The cycloalkenyl may be an unsaturated, preferably C_{5-6}, alicyclic ring having a double bond, such as cyclopentenyl, cyclopentadienyl or cyclohexene. The alkynyl group may be an unsaturated aliphatic hydrocarbon group having a triple bond, such as ethynyl. The alkoxy group may be a group formed with aliphatic hydrocarbons having an ether linkage therebetween, such as methoxy. The alkylthio group may be a group in which sulfur is substituted for oxygen in the ether linkage of alkoxy. The aryl ether may be a group formed with an aromatic hydrocarbon having an ether linkage therebetween, such as phenoxy. The aryl thioether group may be a group in which sulfur is substituted for oxygen in the ether linkage of the aryl ether. The aryl group may be an aromatic hydrocarbon group, such as phenyl, naphthyl, biphenyl, phenanthryl, terphenyl or pyrenyl. The heterocyclic group may be a cyclic group having at least one atom other than carbon, such as furyl, thienyl, oxazolyl, pyridyl, quinolyl, carbazolyl, thiazolyl, imidazolyl, phenanthrolinyl, pyrrolyl, diazolyl or triazolyl. The halogen atom may be mean fluorine, chlorine, bromine or iodine. The haloalkane, haloalkene and haloalkyne groups may be groups in which halogens are substituted for part or entirety of the above-described alkyl, alkenyl, or alkynyl. The aldehyde, carbonyl, ester, carbamoyl or amino groups include groups having, for example, an aliphatic hydrocarbon, an alicyclic ring, an aromatic hydrocarbon or a heterocycle therein, all of which may be as defined above. The silyl group may be a silicon-containing group such as trimethylsilyl. Each of the above-described groups may be unsubstituted or, wherever possible substituted. In particular, the alkyl, cycloalkyl aryl and heterocyclic groups of R^1, R^2 and L, the aryl groups of Ar^1 to Ar^5 and the fused aromatic rings and the alicyclic rings may be unsubstituted or substituted, especially by an alkyl group having at least 4, more especially from 4 to 25, carbon atoms.

[0017] Boron complexes represented by chemical formula (2) and regarded as metal complexes with the chemical formula (1), have particularly high fluorescence quantum yield,

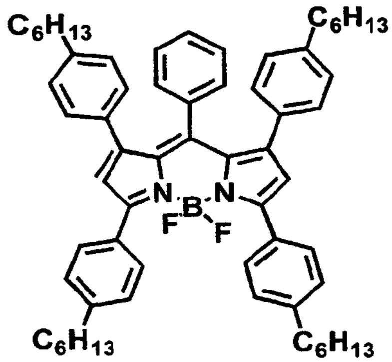


(2)

wherein each of R^3 to R^6, which may be the same as or different from one another, is a group selected from hydrogen, alkyl, cycloalkyl, aralkyl, alkenyl, cycloalkenyl, alkynyl, hydroxyl, mercapto, alkoxy, alkylthio, aryl ethers, aryl thioethers, aryl, heterocyclic, halogens, haloalkane, haloalkene, haloalkyne, cyano, aldehyde, carbonyl, carboxyl, esters, carbamoyl, amino, nitro, silyl, siloxanyl, and fused aromatic and alicyclic rings each formed with an adjacent group selected from R^3 to R^6. Each of Ar^6 to Ar^{10}, independently of each other, is an optionally substituted aryl group or any of Ar^6 to Ar^9, together with an adjacent group selected from R^3 to R^6 and Ar^6 to Ar^9, may form a fused aromatic or alicyclic ring. These substituents are the same as in the chemical formula (1).

[0018] By substituting alkyl having 4 or more, preferably up to 25, carbon atoms into at least one of Ar^1 to Ar^4 of the formula (1) or into at least one of Ar^6 to Ar^9 of the formula (2), the dispersibility of the material is improved and thus high luminance can be obtained. Preferably, both R^5 and R^6 of the formula (2) are fluorine, having regard to availability and the synthesis of primary materials. Examples of the pyrromethene metal complexes are represented by the following formulae.

(1)



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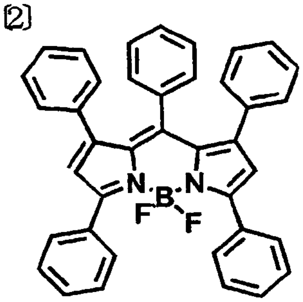

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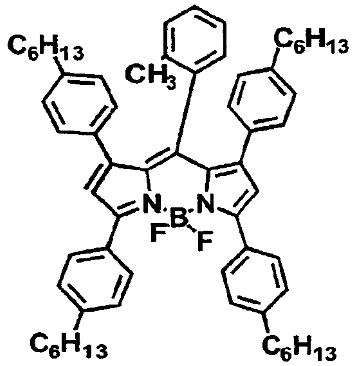

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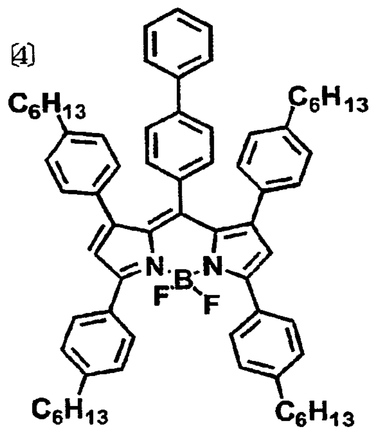

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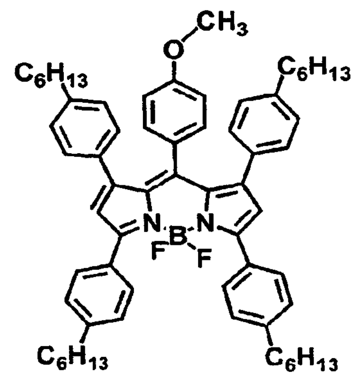

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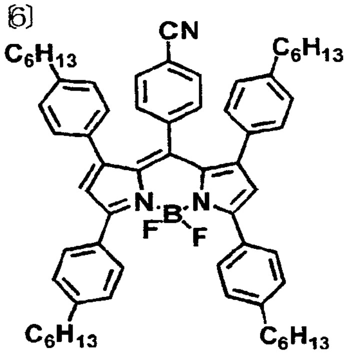

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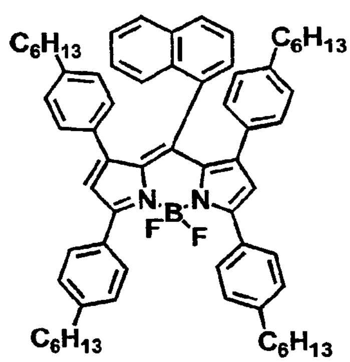

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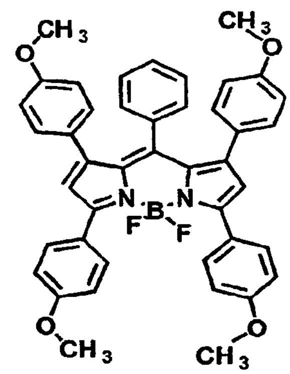

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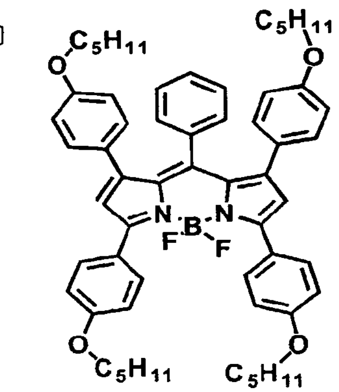

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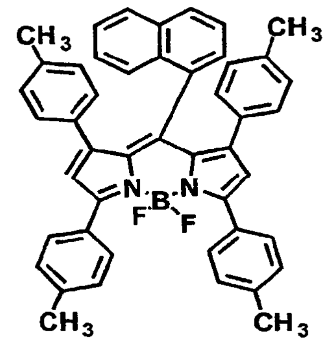

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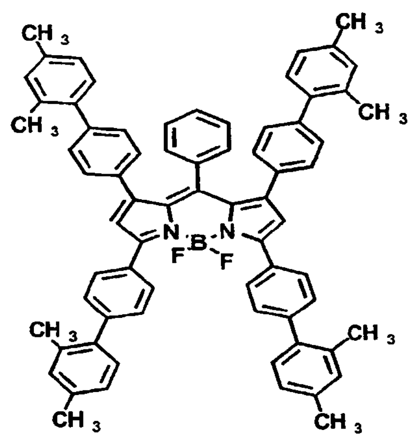

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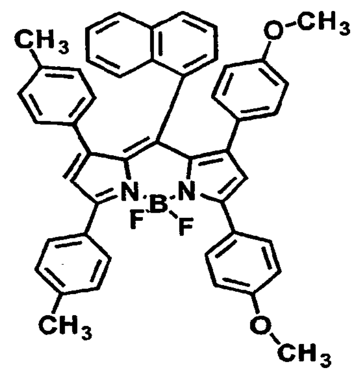

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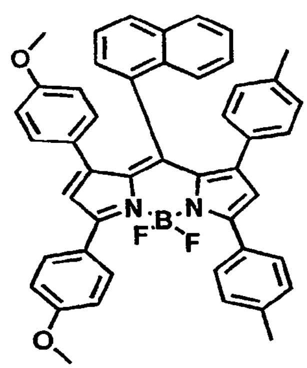

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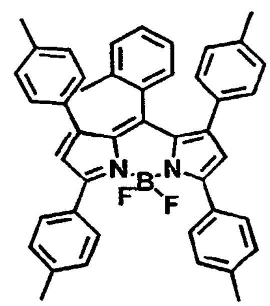

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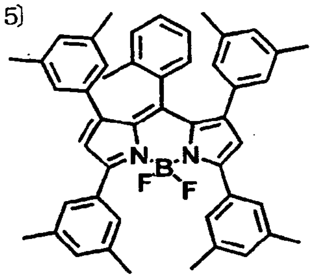

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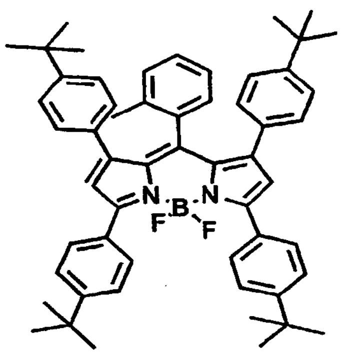

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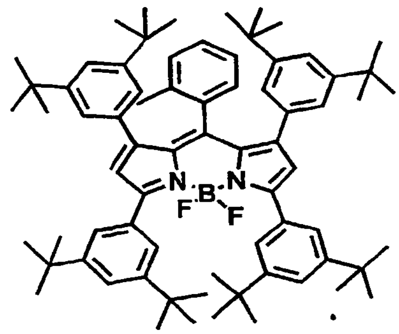

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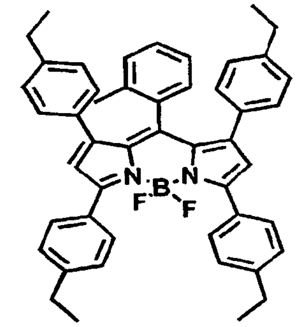

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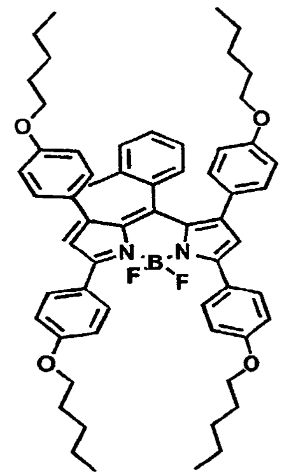

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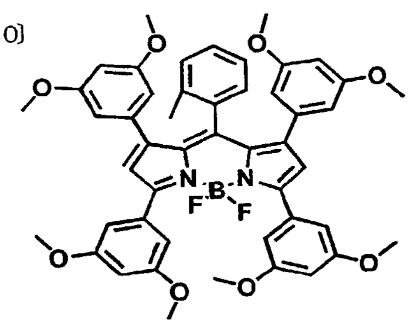

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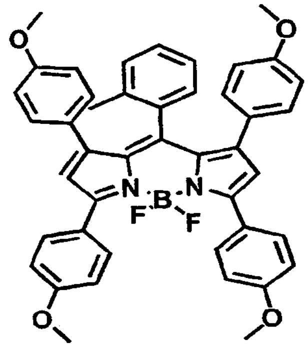

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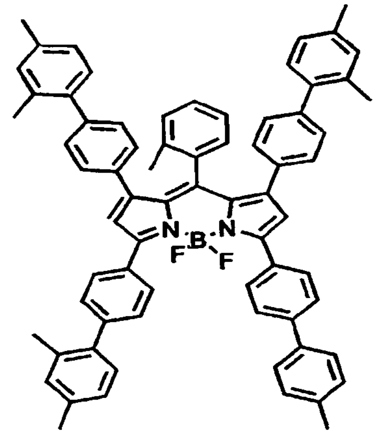

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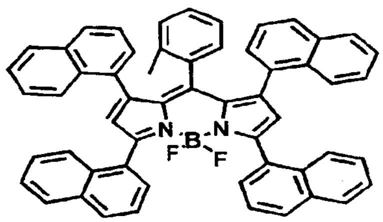

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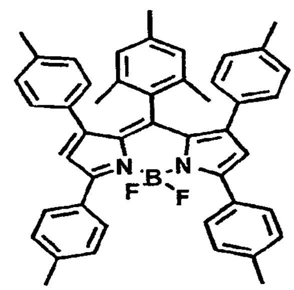

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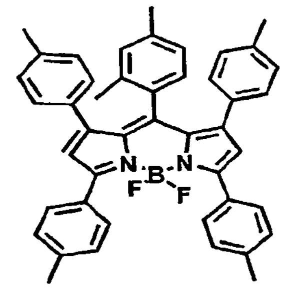

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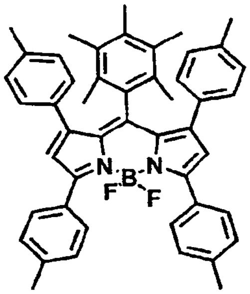

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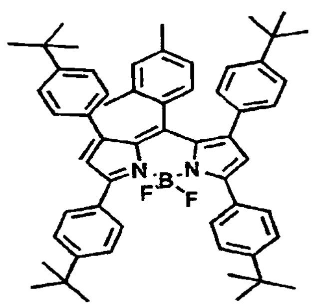

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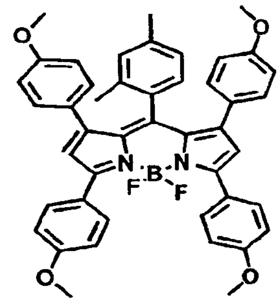

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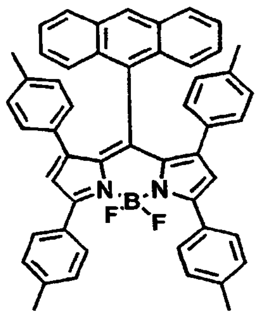

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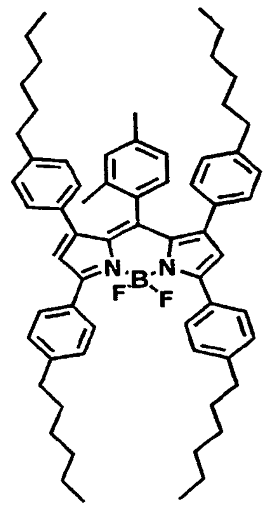

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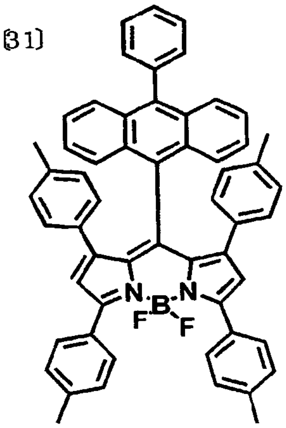

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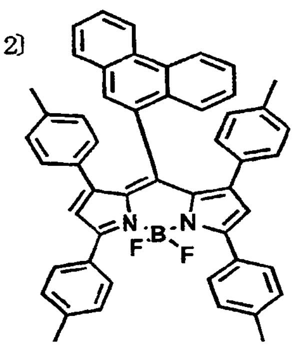

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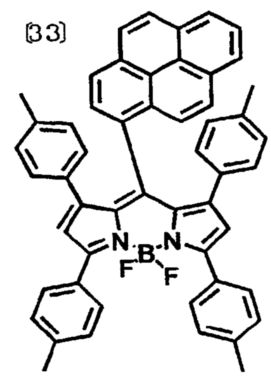

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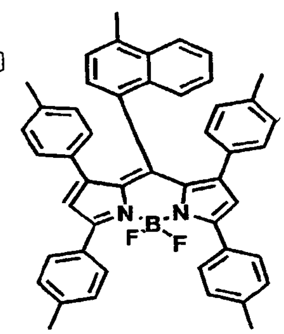

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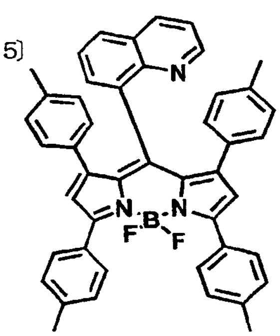

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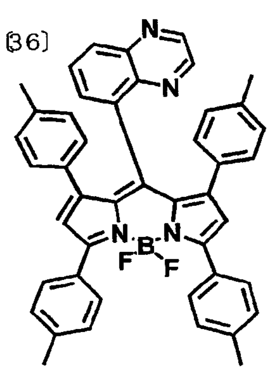

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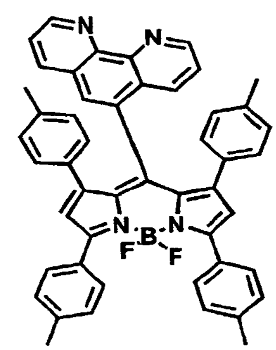

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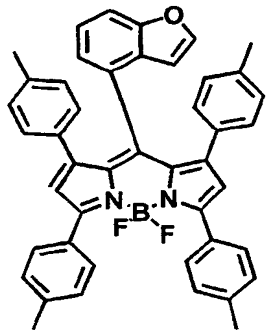

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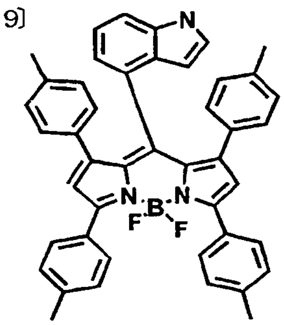

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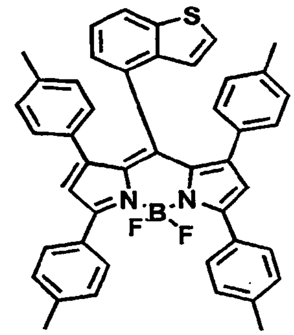

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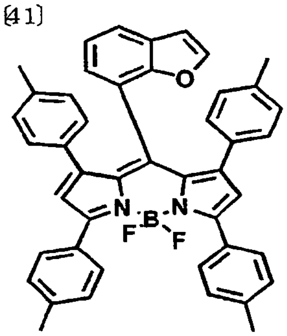

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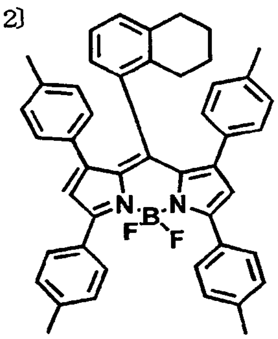

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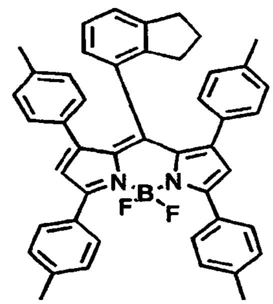

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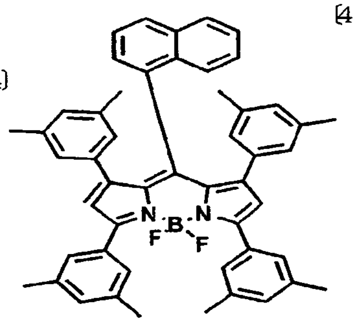

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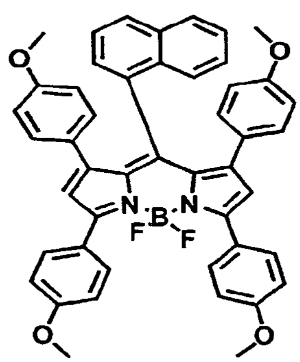

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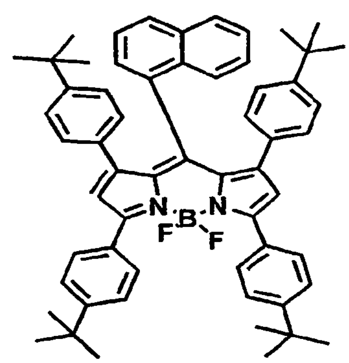

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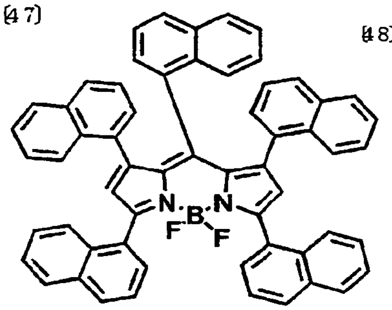

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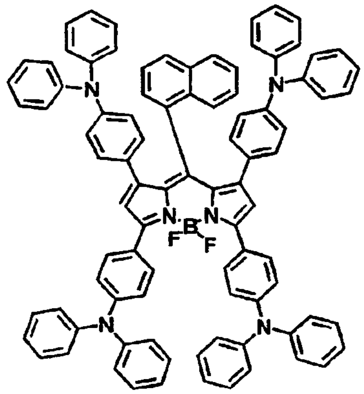

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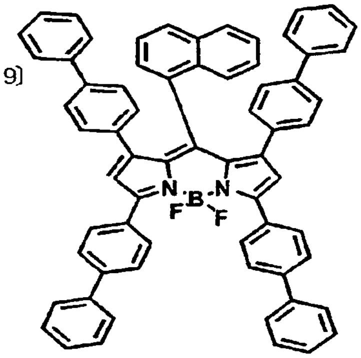

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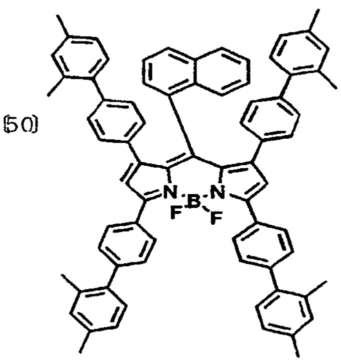

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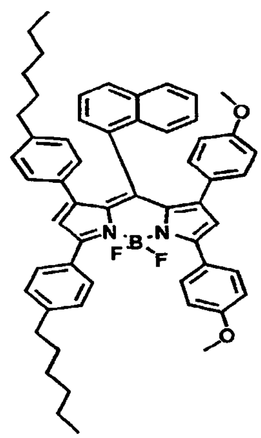

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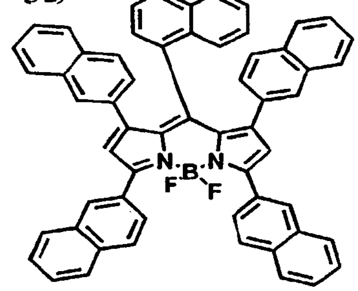

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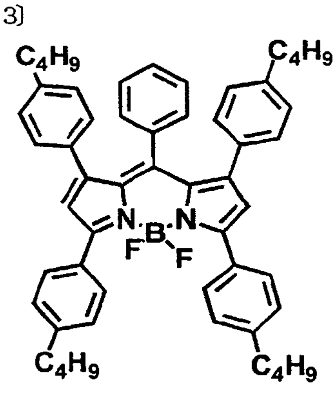

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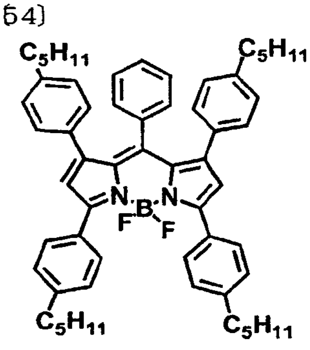

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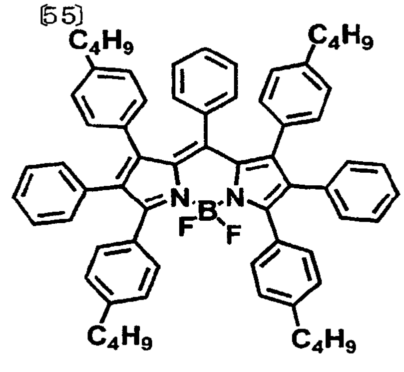

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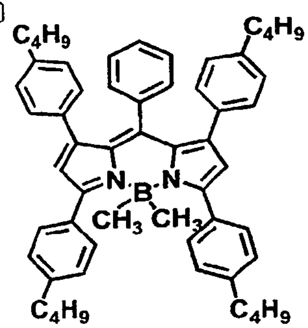

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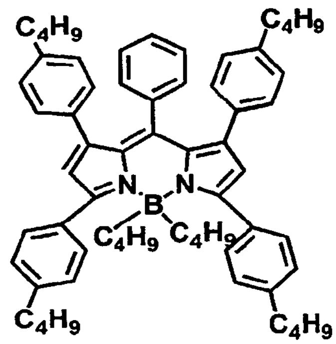

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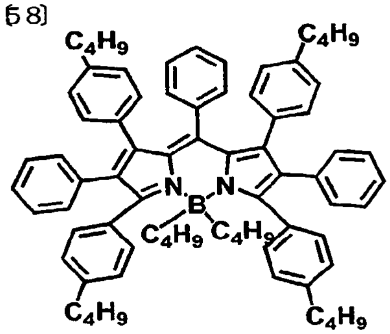

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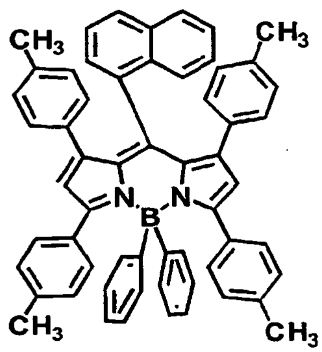

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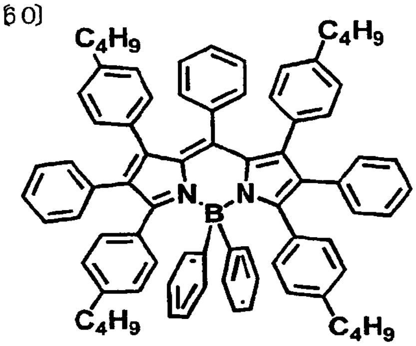

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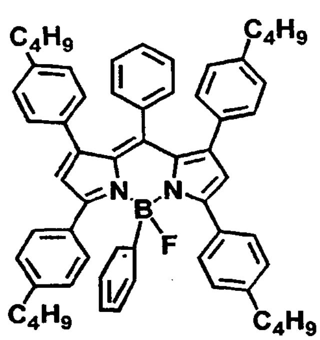

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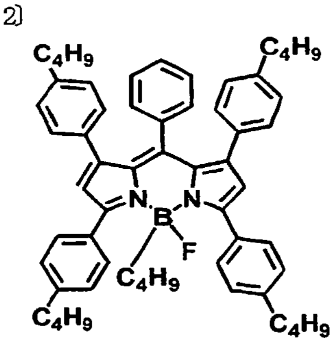
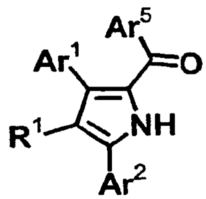


[0019] A pyrromethene metal complex of the present invention may be prepared in accordance with the following procedure.

[0020] A compound represented by the formula (7) or (8) is heated with phosphorus oxychloride in 1,2-dichloroethane, followed by reaction with a compound represented by the formula (9) in the presence of triethylamine. Thus, a metal complex represented by formula (1) is obtained. Ar^1 to Ar^5, R^1 and R^2, M, L, and m are as defined above. J represents a halogen atom.



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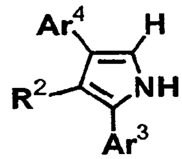


(8)

$$J—M—(L)_{m-1} \tag{9}$$

[0021] A pyrromethene metal complex embodying the present invention so prepared is suitable for an LED material. An LED embodying the present invention will now be described in detail.

[0022] An anode is formed of a transparent material to transmit light. Examples of materials of the anode include conductive metal oxides such as tin oxide, indium oxide and indium tin oxide (ITO); metals such as gold, silver and chromium; conductive inorganic compounds such as copper iodide and copper sulfide; and conductive polymers such as polythiophene, polypyrrole and polyaniline. In particular, ITO glass and Nesa glass are preferably used. The resistance of the transparent anode is not limited as long as current can be supplied to ensure that light is emitted from the device, but preferably, it is low with respect to power consumption of the device. For example, a substrate with ITO having a resistance of 300 Ω/□ or less is used for the anode. The thickness of the ITO anode is set according to the resistance thereof and often set in the range of 100 to 300 nm. A glass substrate is formed of, for example, soda-lime glass or alkali-free glass. The thickness of the glass substrate may be 0.5 mm or more to ensure the mechanical strength of the device. Preferably, alkali-free glass is used because few ions are eluted therefrom. Alternatively, soda-lime glass coated with SiO_2 may be used. However, the substrate is not limited to being formed of glass as long as the stable function of the anode can be ensured, and the anode may be formed of a plastics material. ITO may be deposited by, for example, an electron beam, sputtering or a chemical reaction method.

[0023] A cathode is preferably formed of a material capable of efficiently injecting electrons into an organic layer. Examples of cathode materials include platinum, gold, silver, copper, iron, tin, aluminum, indium, chromium, lithium, sodium, potassium, calcium, magnesium, cesium and strontium. In order to increase the electron-injection efficiency to improve the performance of the device, metals having a low work function, such as lithium, sodium, potassium, calcium, cesium and magnesium, and alloys containing these metals are advantageously used. However, generally speaking, these metals having a low work function are generally unstable in the air, so for example the method of using a highly stable electrode and doping the organic layer with a small amount of lithium, magnesium, or cesium (1 nm or less in thickness when measured by a thickness meter on vacuum deposition) can be given as a preferred example. Alternatively, inorganic salts such as lithium fluoride may be used. In order to protect the cathode, preferably, a metal such as platinum, gold, silver, copper, iron, tin, aluminium or indium or an alloy of these metals, an inorganic substance such as silica, titania or silicon nitride, and a polymer such as polyvinyl alcohol, polyvinyl chloride or a hydrocarbon are further laminated. Preferably, the cathode is formed by a method in which the conductivity can be ensured, such as resistance heating, electron beam, sputtering, ion plating, or coating.

[0024] The material which brings about light emission in a light emitting device embodying the present invention may take the form of a composition or one or more layers comprising the following respective components, namely a hole transporting material, an emissive material, an electron transporting material and a hole-blocking material and, in particular may comprise: (1) a hole transporting layer and an emissive layer; (2) a hole transporting layer, an emissive layer and an electron transporting layer; (3) an emissive layer and an electron transporting layer; (4) a hole transporting layer, an emissive layer and a hole-blocking layer; (5) a hole transporting layer, an emissive layer, a hole-blocking layer, and an electron transporting layer; (6) an emissive layer, a hole-blocking layer and an electron transporting layer; or (7) a monolayer containing some of the materials of the above-described layers. Hence, the LED may have a multilayer structure of (1) to (6) or a monolayer structure composed of an LED material alone or including an LED material and

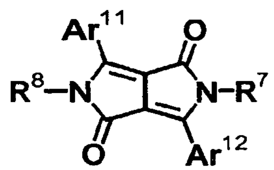
a material of the hole transporting layer, the hole-blocking layer or the electron transporting layer. The material which brings about light emission, in the present invention, may be a composition or layer contributing to the light emission of the device, and may emit light itself or may help to emit light.

[0025] The material of the present invention may comprise a diketopyrrolo[3,4-c]pyrrole derivative having a specific structure and an organic fluorescent material having a fluorescent peak wavelength of 580 to 720 nm. Alternatively, the material may comprise a pyrromethene metal complex or composition containing it. These materials may be present in any layer of the above-described layers, and preferably, are present in the emissive layer because both materials are fluorescent.

[0026] The hole transporting layer serves to transport holes injected from the anode. Examples of hole transporting materials include: triphenylamines, such as N,N'-diphenyl-N,N'-bis(3-methylphenyl)-4,4'-diphenyl-1,1'-diamine and N, N'-bis(1-naphthyl)-N,N'-diphenyl-4,4'-dipheny-1,1'-diamine; bis(N-arylcarbazole) and bis(N-alkylcarbazole) derivatives; and pyrazolines, stilbenes, distyryl derivatives, hydrazones, heterocyclic compounds, such as oxadiazoles, phthalocyanines, and porphyrins; and polymers, such as polycarbonates and styrenes having a monomer of the above-described compounds as a side chain group, polyvinyl carbazole, and polysilanes. However, the hole transporting materials are not limited to these as long as they can be formed into a thin film and do not inhibit the transporting of holes injected from the anode. The hole transporting layer may be formed of one of the above-described materials alone, or may be formed of a plurality of materials.

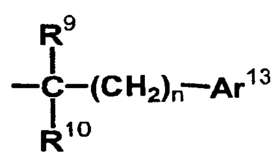
[0027] The emissive layer is provided with an LED material. The LED of the present invention emits light having a peak wavelength of 580 to 720 nm by electrical energy. A light having a peak wavelength less than 580 nm cannot lead to red emission with excellent chromatic purity even if the peak width thereof is small. On the other hand, a light having a peak wavelength greater than 720 nm leads to a degraded luminous efficacy and therefore, cannot provide red emission with a high luminance. The emissive material comprises at least one of the following (a) and (b).

(a) a diketopyrrolo[3,4-c]pyrrole derivative represented by formula (3) and an organic fluorescent material having a peak fluorescent wavelength of 580 to 720 nm, which formula (3) is:



(3)

wherein each of R^7 and R^8, independently of each other, is a group selected from C_{1-25} alkyl groups and groups represented by formula (4):



(4)

wherein each of R^9 and R^{10}, independently of each other, is a group selected from hydrogen, C_{1-4} alkyl and phenyl having no substituent or substituted by C_{1-3} alkyl. Ar^{13} is a group selected from phenyl and naphthyl each substituted by alkyl or alkoxy or halogen or phenyl, and unsubstituted naphthyl. n represents zero or a whole number of 1 to 4. Each of Ar^{11} and Ar^{12}, independently of each other, is a group selected from phenyl, naphthyl, styryl and carbazolyl; and

(b) a pyrromethene metal complex represented by the above-described formula (1).

[0028] In the case of (a), a diketopyrrolo[3,4-c]pyrrole derivative represented by formula (3) and an organic fluorescent material having a peak fluorescent wavelength of 580 to 720 nm are used as both a dopant and a host. Preferably, the diketopyrrolo[3,4-c]pyrrole derivative is used as a host and the organic fluorescent material is used as a dopant.

[0029] The compounds represented by formulae (3) and (4) will now be described in detail. The C_{1-25} alkyl groups of R^7 and R^8 may have a straight chain or a side chain. Specifically, R^7 and R^8 may then be methyl, ethyl, n-propyl, isopropyl, n-butyl, sec-butyl, isobutyl, tert-butyl, n-pentyl, 2-pentyl, 3-pentyl, 2,2-dimethylpropyl, n-hexyl, n-heptyl, n-

octyl, 1,1,3,3-tetramethylbutyl, 2-ethylhexyl, n-nonyl, decyl, undecyl, dodecyl, tetradecyl, pentadecyl, hexadecyl, heptadecyl, octadecyl, eicosyl, heneicosyl, docosyl, tetracosyl and pentacosyl. Preferably, R^7 and R^8 are C_{1-8} alkyl groups, for example, methyl, ethyl, n-propyl, isopropyl, n-butyl, sec-butyl, isobutyl, tert-butyl, n-pentyl, 2-pentyl, 3-pentyl, 2,2-dimethylpropyl, n-hexyl, n-heptyl, n-octyl, 1,1,3,3-tetramethylbutyl, and 2-ethylhexyl. More preferably, R^7 and R^8 are C_{1-4} alkyl groups, for example, methyl, ethyl, n-propyl, isopropyl, n-butyl, sec-butyl, isobutyl and tert-butyl.

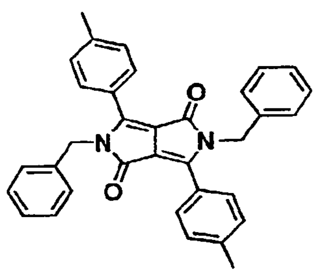
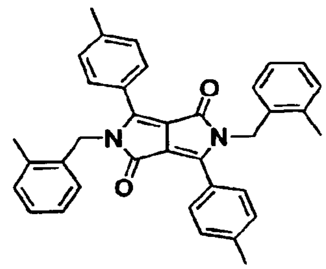
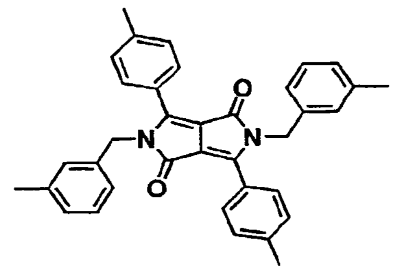
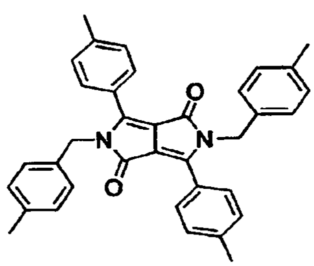
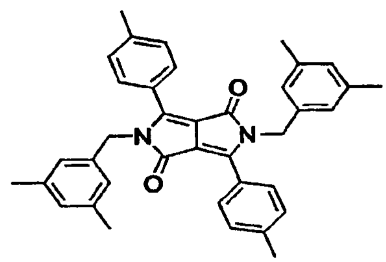
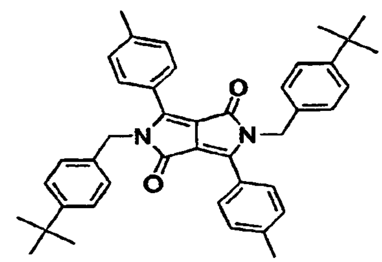
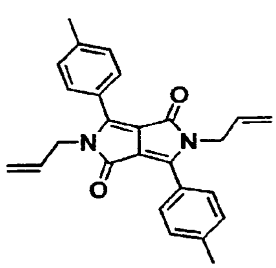
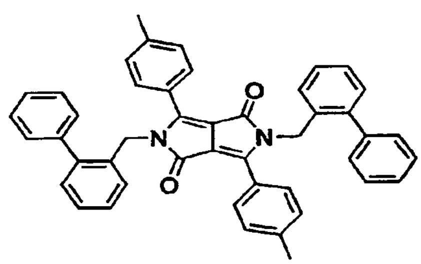
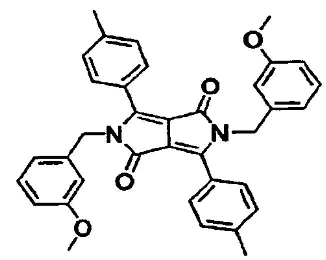
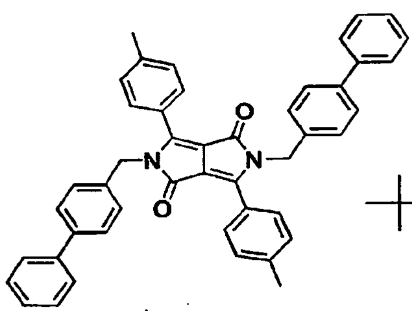
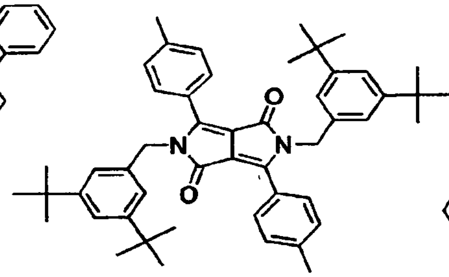
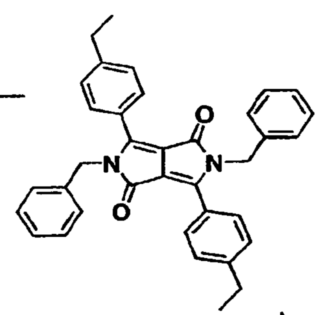
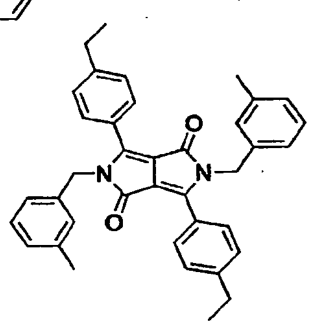
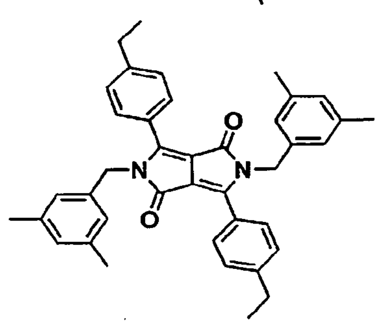
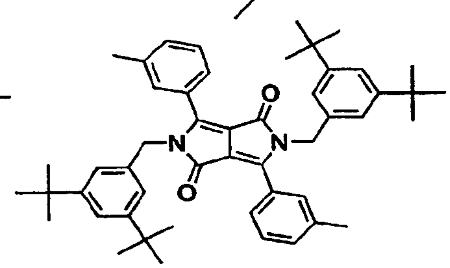
[0030] The C_{1-4} alkyl groups of R^9 and R^{10} may be methyl, ethyl, n-propyl, isopropyl, n-butyl, sec-butyl, isobutyl or tert-butyl. The phenyl groups of R^9 and R^{10} may be substituted by C_{1-3} alkyl groups, and the C_{1-3} alkyl group may be methyl, ethyl, n-propyl or isopropyl. The phenyl groups of Ar^{13} are substituted by at least one of alkyl, alkoxy, halogen and phenyl and may have any of these substituents at up to three bonding sites, whether the substituents are the same as or different from one another. In this instance, preferably, the alkyl substituted is a C_{1-8} alkyl. Specifically, this alkyl substituent includes methyl, ethyl, n-propyl, isopropyl, n-butyl, sec-butyl, isobutyl, tert-butyl, n-pentyl, 2-pentyl, 3-pentyl, 2,2-dimethylpropyl, n-hexyl, n-heptyl, n-octyl, 1,1,3,3-tetramethylbutyl and 2-ethylhexyl. The alkoxy substituent is preferably a C_{1-8} alkoxy substituent and specifically may be methoxy, ethoxy, n-propoxy, isopropoxy, n-butoxy, sec-butoxy, isobutoxy, tert-butoxy, n-pentoxy, 2-pentoxy, 3-pentoxy, 2,2-dimethylpropoxy, n-hexoxy, n-heptoxy, n-octoxy, 1,1,3,3-tetramethylbutoxy and 2-ethylhexoxy. The halogen substituent may be fluorine, chlorine, bromine or iodine. The phenyl substituent on the phenyl group of Ar^{13} may be further substituted by a C_{1-8} alkyl or C_{1-8} alkoxy group. These alkyl and alkoxy groups are the same as above. The naphthyl group represented by Ar^{13} may be a 1-naphthyl or 2-naphthyl, and may have any substituent and preferably the same substituents as on the above-described phenyl groups.

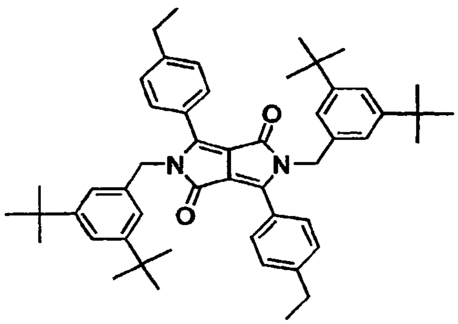
[0031] Ar^{11} and Ar^{12} are groups selected from phenyl, naphthyl, styryl and carbazolyl. The naphthyl, styryl and carbazolyl groups may serve as groups each including a conjugated bond, which groups each interconnect respective diketopyrrolo[3,4-c]pyrrole skeletons at any of respective bonding sites on such an interconnecting group to provide a dimer or oligomer having two or more such skeletons. These phenyl, naphthyl, styryl and carbazolyl groups may have thereon a substituent selected from hydrogen, cyano, halogen, alkyl, cycloalkyl, aralkyl, alkoxy, alkylthio, aryloxy, aryl thioether, aryl, heterocyclic, amino, silyl and fused aromatic and alicyclic rings each formed with an adjacent substituent. The halogen atom may be the same as those mentioned above. The alkyl groups may have a straight chain or a side chain and are preferably C_{1-25} alkyl, more preferably C_{1-8} alkyl.

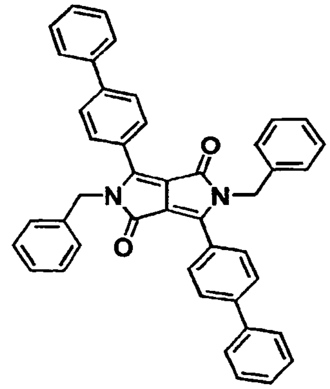
Examples of alkyl groups are described above. The cycloalkyl groups are preferably C_{5-12} cycloalkyl and specifically include cyclopentyl, cyclohexyl, cycloheptyl, cyclooctyl, cyclononyl, cyclodecyl, cycloundecyl and cyclododecyl. More preferably, the cycloalkyl groups include cyclopentyl, cyclohexyl, cycloheptyl and cyclooctyl. The aralkyl groups are preferably C_{7-24} aralkyl.

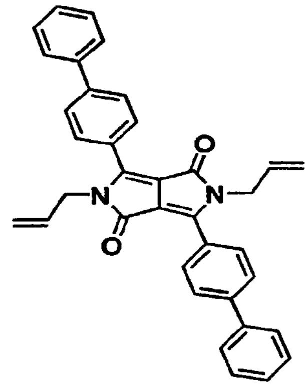
Specifically, they include benzyl, 2-benzyl-2-propyl, β-phenyl-ethyl, α,α-dimethylbenzyl, ω-phenyl-butyl, ω,ω-dimethyl-ω-phenyl-butyl, ω-phenyl-dodecyl, ω-phenyl-octadecyl, ω-phenyl-eicosyl and ω-phenyl-docosyl groups. Preferably, they are benzyl, 2-benzyl-propyl, β-phenyl-ethyl, α,α-dimethylbenzyl, ω-phenyl-butyl, ω,ω-dimethyl-ω-phenyl-butyl, ω-phenyl-dodecyl, and ω-phenyl-octadecyl groups, and more specifically are benzyl, 2-benzyl-propyl, β-phenyl-ethyl, α,α-dimethylbenzyl, ω-phenyl-butyl, and ω,ω-dimethyl-ω-phenyl-butyl groups. The alkylthio groups are substituents in which oxygen in the ether linkage of an alkoxy group is replaced with sulfur. The aryloxy groups may be any substituents formed with aromatic hydrocarbons having an ether linkage therebetween. In addition, in the present invention, the aryloxy groups include substituents formed with a C_{6-24} aromatic hydrocarbon and a saturated or unsaturated heterocycle which have an ether linkage therebetween. This hydrocarbon and heterocycle may have no substituent or be substituted by C_{1-8} alkyl or C_{1-8} alkoxy. The aryl thioether groups may be any substituents in which oxygen in the ether linkage of an aryloxy group is replaced with sulfur. The aryl groups are preferably C_{6-24} aryl groups, and specifically include phenyl, 1-naphthyl, 2-naphthyl, 4-biphenyl, phenanthryl, 2-fluorenyl, 9-fluorenyl, 2-anthracenyl and 9-anthracenyl. More preferably, the aryl groups include phenyl, 1-naphthyl, 2-naphthyl and 4-biphenyl. These aryl groups may be further substituted by C_{1-8} alkyl or C_{1-8} alkoxy. The heterocyclic groups have a cyclic structure having at least one atom other than carbon, such as nitrogen, oxygen or sulfur. They may be saturated or unsaturated and preferably unsaturated. Specifically, they include thienyl, benzo[b]thienyl, dibenzo[b,d]thienyl, thianthrenyl, furyl, furfuryl, 2H-pyranyl, benzofuranyl, isobenzofuranyl, dibenzofuranyl, phenoxythienyl, pyrrolyl, imidazolyl, pyrazolyl, pyridyl, bipyridyl, triazinyl, pyrimidinyl, pyrazinyl, pyridazinyl, indolizinyl, isoindolyl, indolyl, indazolyl, purinyl, quinolizinyl, quinolyl, isoquinolyl, phthalazinyl, naphthyridinyl, quinoxalinyl, quinazolinyl, quinolinyl, phthalizinyl, carbazolyl, carbolinyl, benzotriazolyl, benzoxazolyl, phenanthridinyl, acridinyl, perimidinyl, phenanthrolinyl, phenazinyl, isothiazolyl, phenothiazinyl, isoxazolyl, furazanyl and phenoxazinyl. These heterocycle groups may be further substituted by C_{1-8} alkyl or C_{1-8} alkoxy. In the amino groups, at least one hydrogen of the two hydrogens thereof may be replaced with C_{1-25} alkyl, C_{5-12} cycloalkyl, aryloxy, which may include a C_{6-24} aromatic hydrocarbon, C_{6-24} aryl or heterocyclic. In this instance, the C_{6-24} aryl and the heterocyclic group may be further substituted by C_{1-8} alkyl or C_{1-8} alkoxy. In the silyl groups, at least one hydrogen of three hydrogens thereof may be replaced with C_{1-25} alkyl, C_{5-12} cycloalkyl, aryloxy including a C_{5-24} aromatic hydrocarbon, C_{6-24} aryl or a heterocyclic group. The C_{6-24} aryl and the heterocyclic group may be further substituted by C_{1-8} alkyl or alkoxy. The fused aromatic ring and alicyclic ring formed with adjacent substituents may be unsubstituted or substituted.

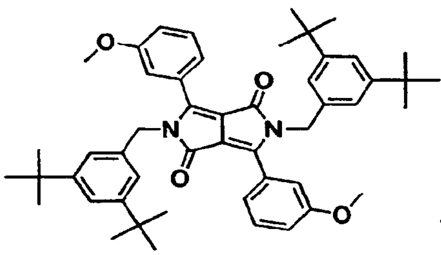
[0032] Preferred diketopyrrolo[3,4-c]pyrrole derivatives include the following:

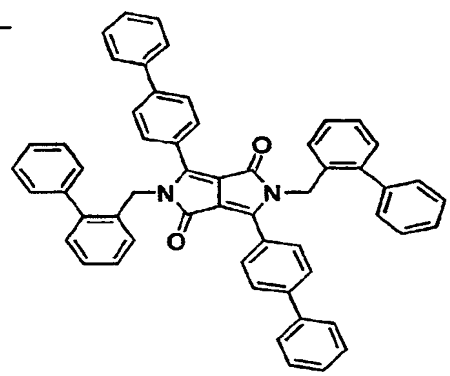
















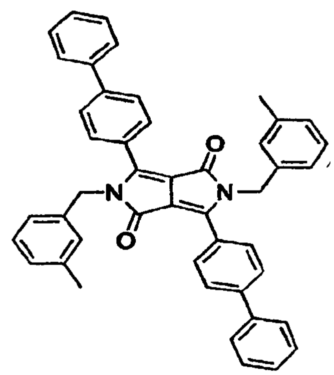


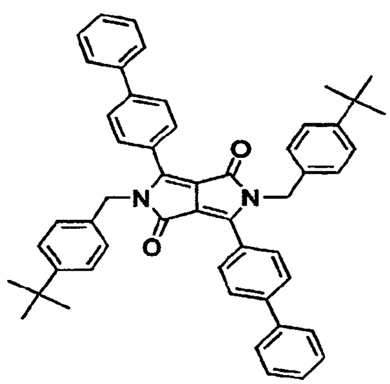


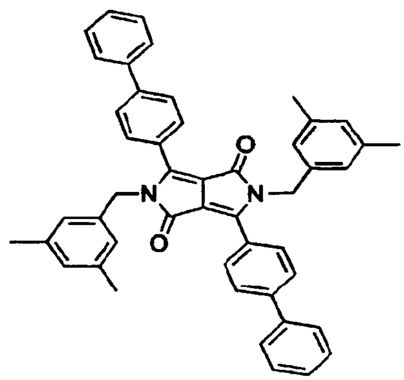


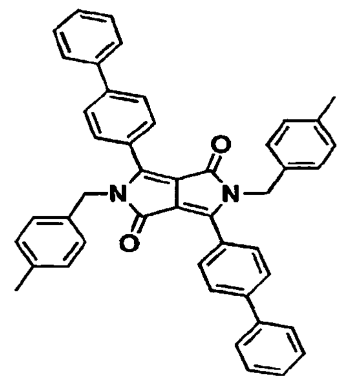


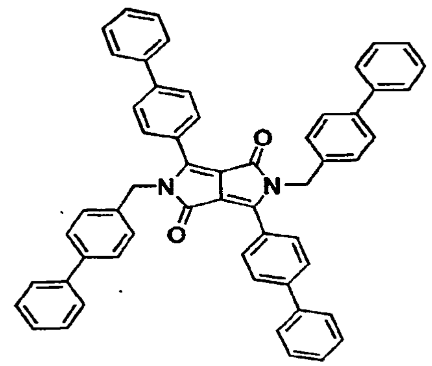


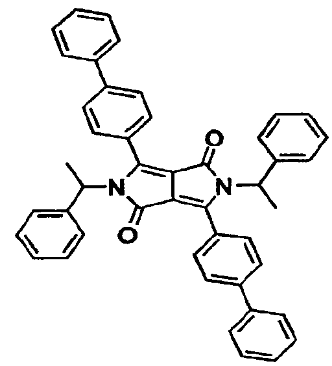


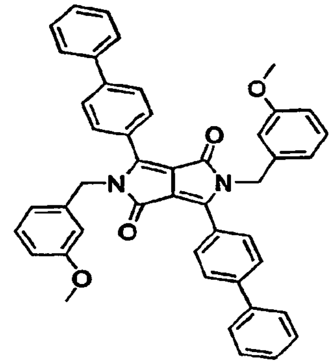


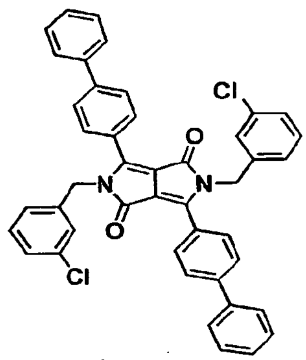


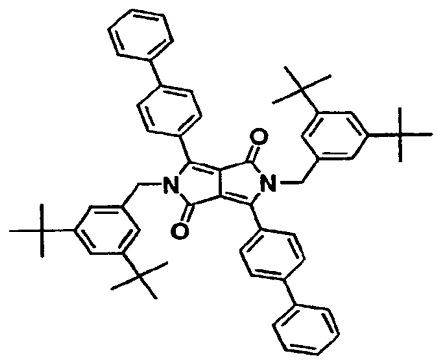


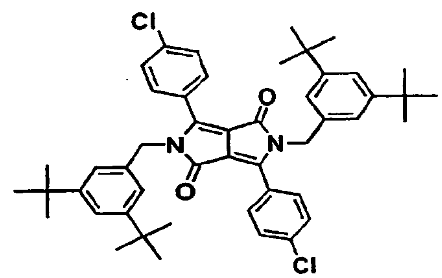


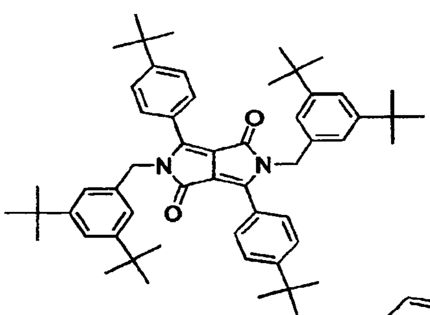


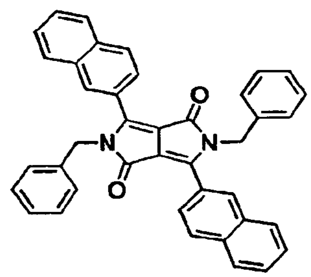


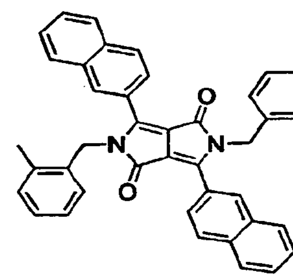


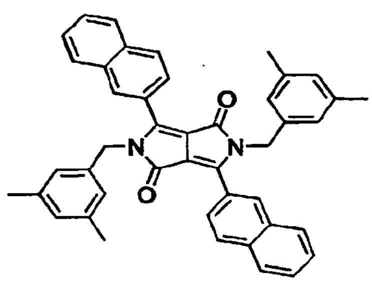


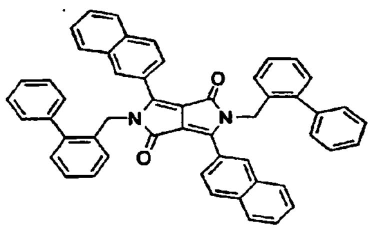


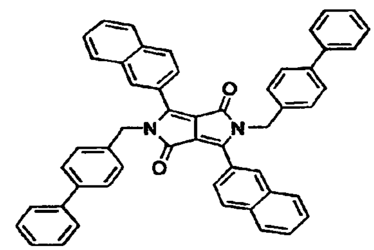


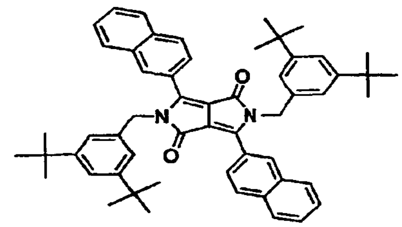


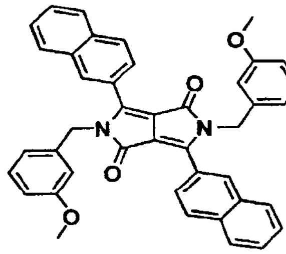


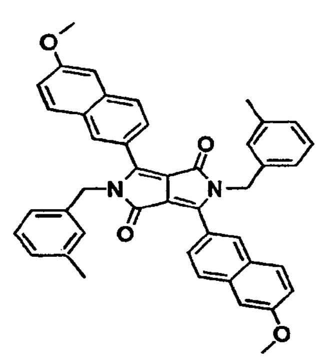


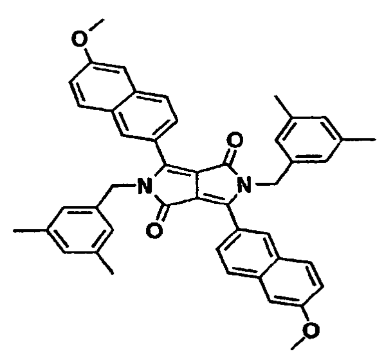


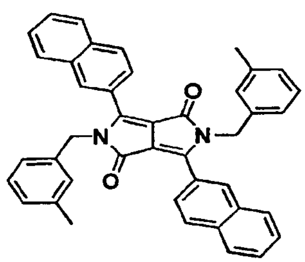


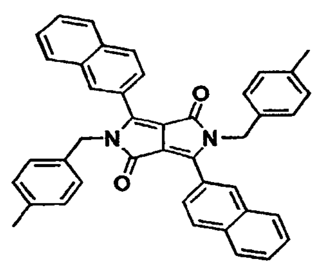


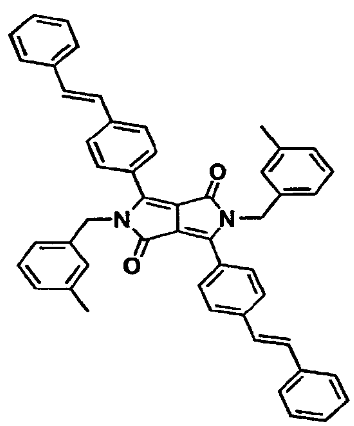


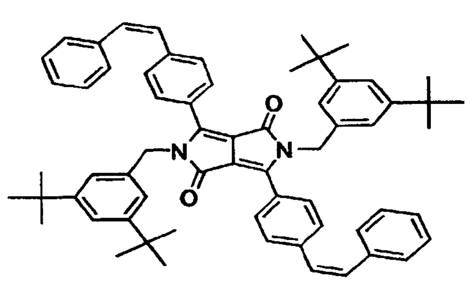


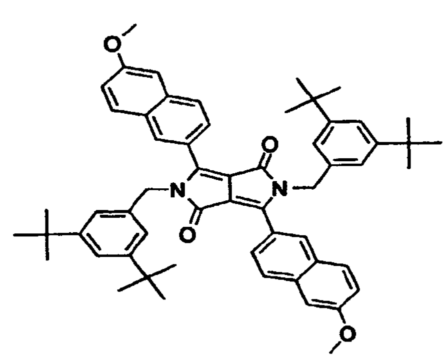


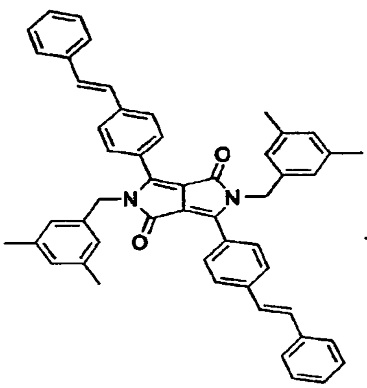


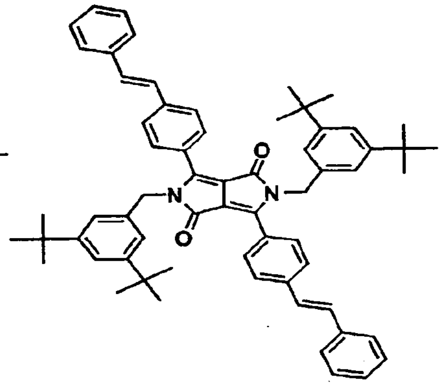


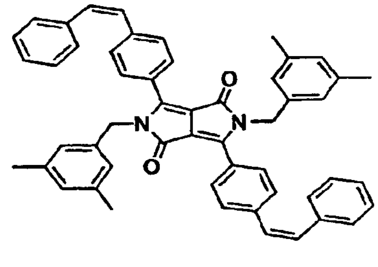


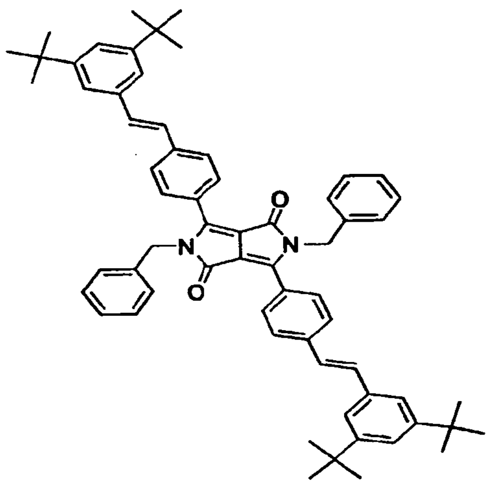


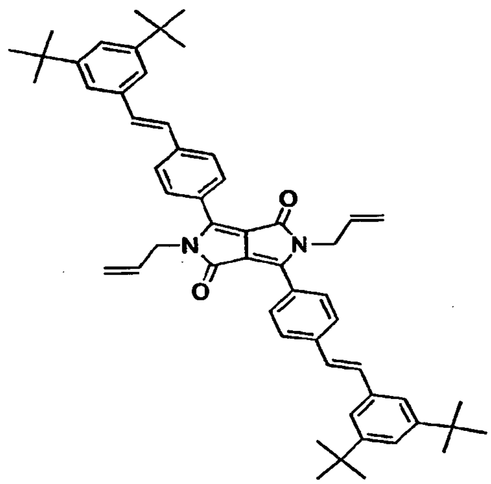


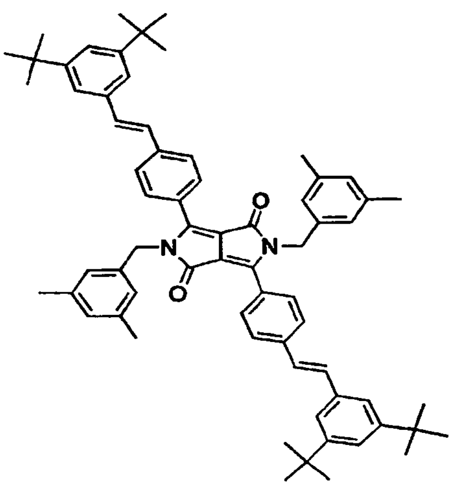


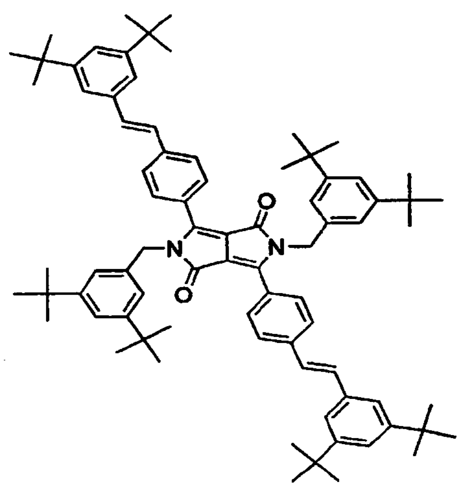


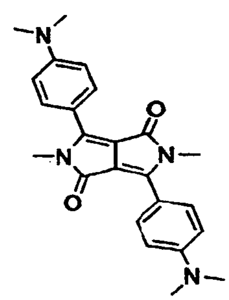


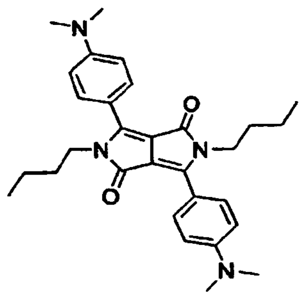


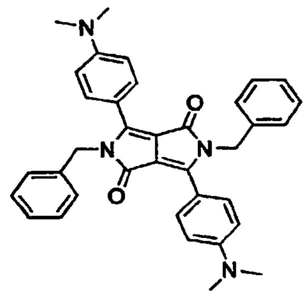


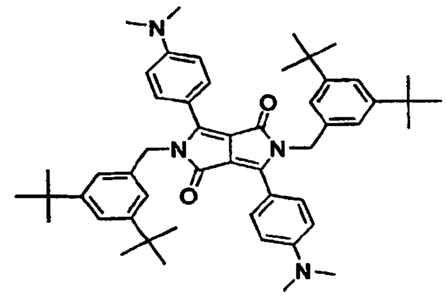


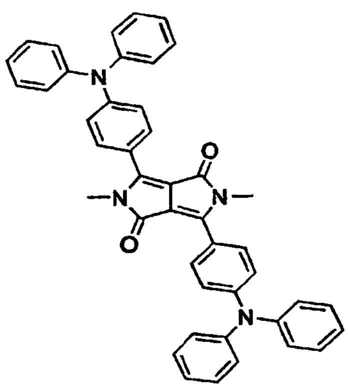


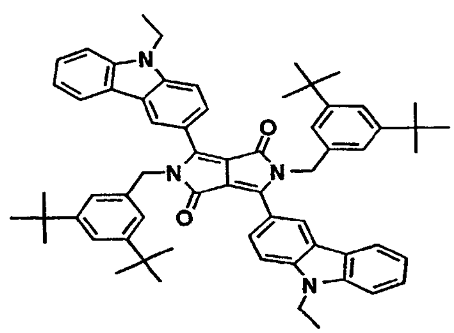


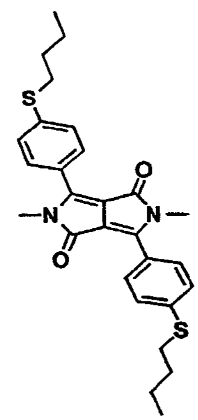


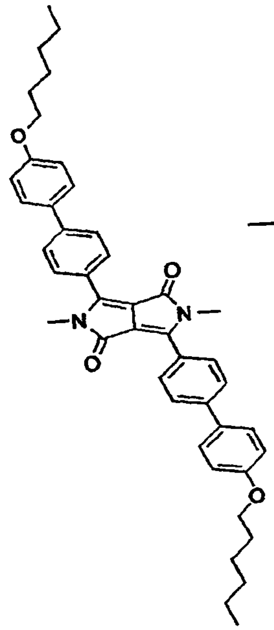


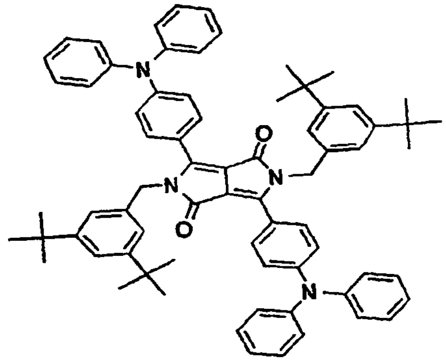


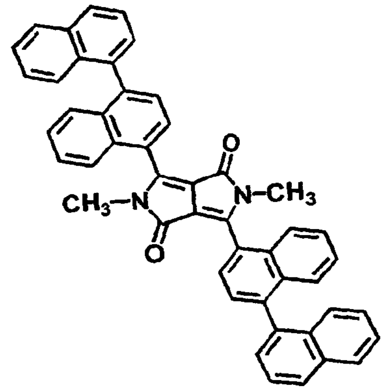


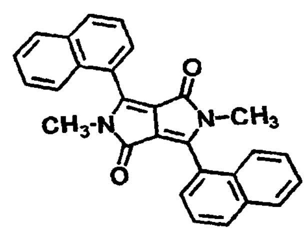


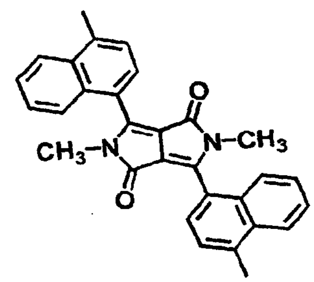


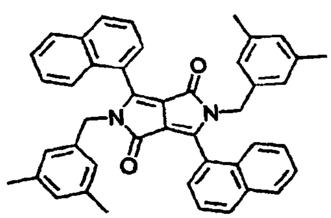


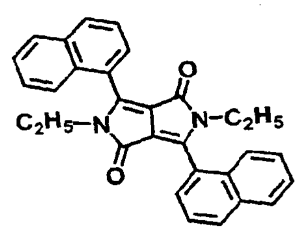


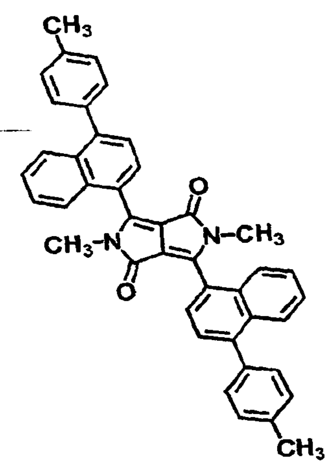


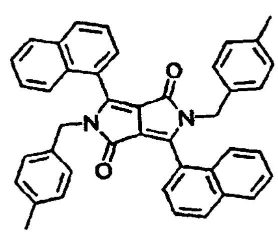


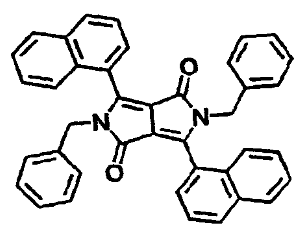


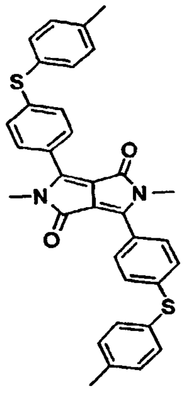
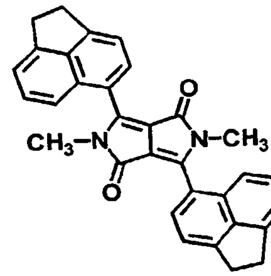
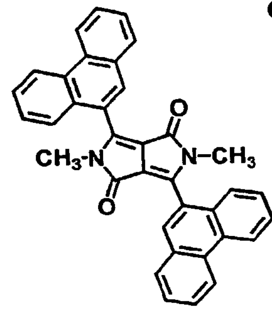
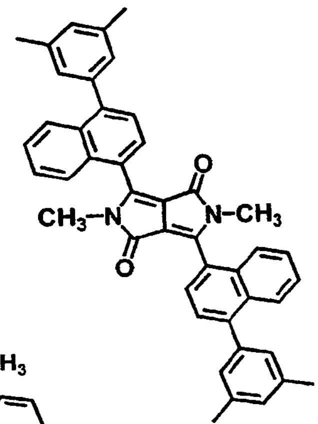
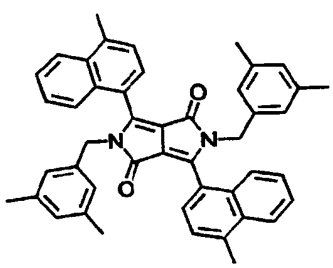
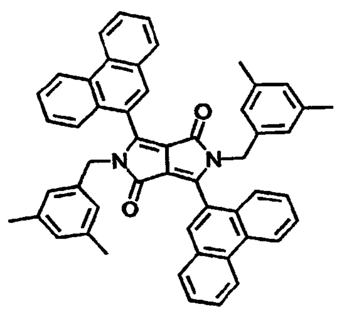
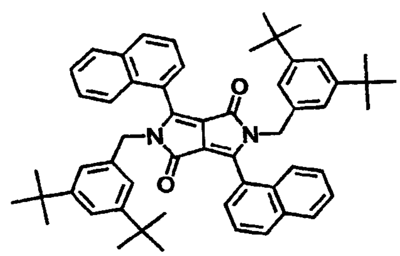
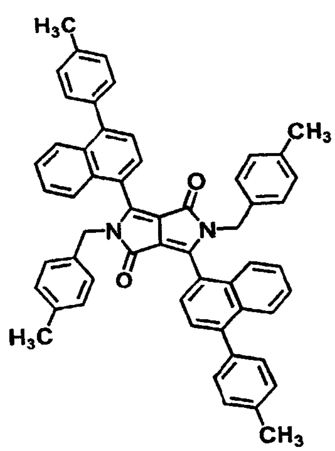
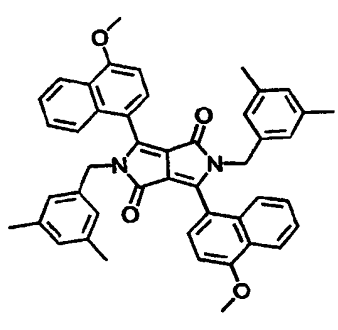
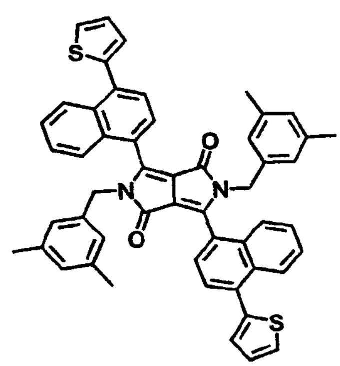


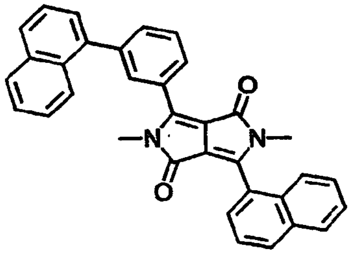
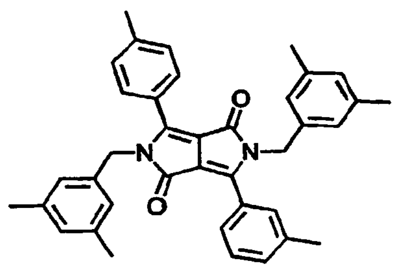
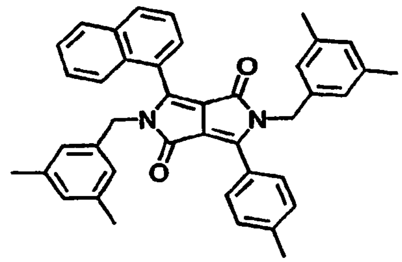


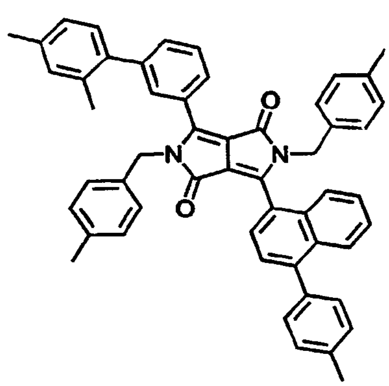
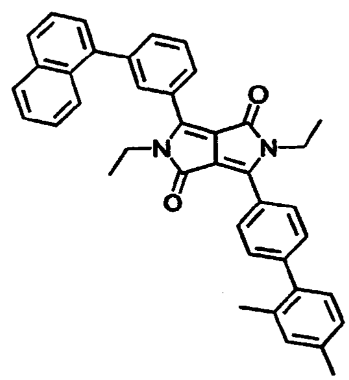
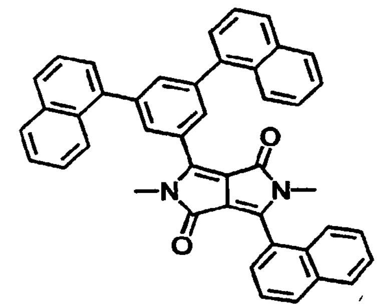


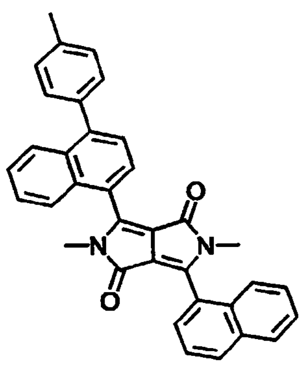
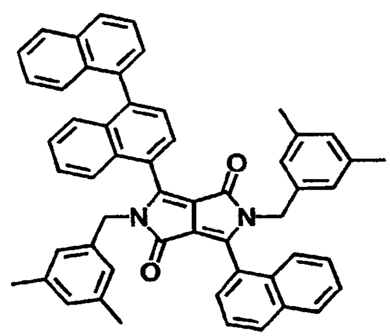
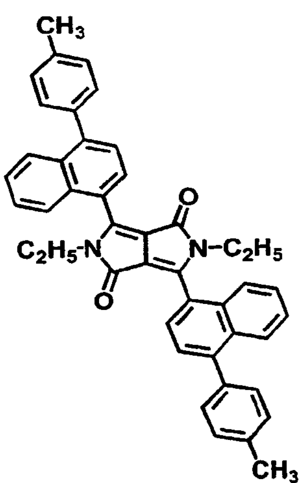




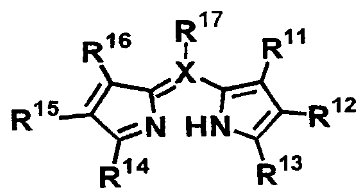
[0033] The diketopyrrolo[3,4-c]pyrrole derivatives are prepared in accordance with, for example, EP-A-0094911 and EP-A-0133156. Aromatic nitrile and diisopropyl succinate are heated together in t-amyl alcohol in the presence of potassium-t-butoxide to prepare a diketopyrrolopyrrole precursor. The diketopyrrolopyrrole precursor is heated with an alkyl halide in dimethylformamide (DMF) in the presence of potassium-t-butoxide and is followed by a general processing, Thus, the diketopyrrolo[3,4-c]pyrrole is obtained.

[0034] The diketopyrrolo[3,4-c]pyrrole derivatives of the present invention are fluorescent, and most of the derivatives have a fluorescence quantum efficiency of 0.3 or more in toluene or DMF or have a molar absorptivity of 5000 or more.

[0035] In the present invention, organic fluorescent materials having a peak wavelength of 580 to 720 nm are used to generate red emission. Specifically, the organic fluorescent materials include fused derivatives of aromatic hydro-

carbons such as terylene; fused heterocyclics such as pyridinothiadiazole, pyrazolopyridine, and diketopyrrolopyrrole; naphthalimido derivatives such as bis(diisopropylphenyl)perylenetetracarboxylic imido; perynones; rare earth complexes such as Eu complexes of which the ligand is acetylacetone or benzoylacetone and phenanthroline; 4-(dicyanomethylene)-2-methyl-6-(p-dimethylaminostyryl)-4H-pyran and the analogues thereof; metal phthalocyanine derivatives such as magnesium phthalocyanine and aluminium chlorophthalocyanine; metalloporphyrin derivatives such as zinc porphyrin; thiophenes; pyrroles; rhodamines; deazaflavin derivatives; coumarin derivatives; oxazines; phenoxazines; phenoxazones; quinacridones; benzothioxanthene and the analogues thereof; and dicyanoethenylarenes.

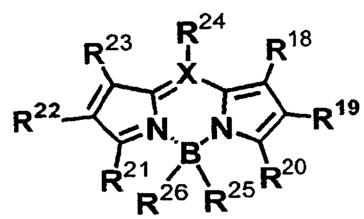
[0036] Preferably, the organic fluorescent materials have a pyrromethene skeleton represented by formula (5) or a metal complex thereof to generate a red emission having excellent chromatic purity, which formula (5) is as follows:



(5)

wherein at least one of R^{11} to R^{17} is an optionally substituted aromatic ring or forms a fused ring with an adjacent substituent; i.e. another group selected from R^{11} to R^{17}. Each other of R^{11} to R^{17} is a group selected from hydrogen, alkyl, cycloalkyl, aralkyl, alkenyl, cycloalkenyl, alkynyl, hydroxyl, mercapto, alkoxy, alkylthio, aryl ethers, aryl thioethers, aryl, heterocyclic, halogens, haloalkane, haloalkene, haloalkyne, cyano, aldehyde, carbonyl, carboxyl, esters, carbamoyl, amino, nitro, silyl, siloxanyl, and fused aromatic and alicyclic rings each formed with adjacent substituent; group selected from R^{11} to R^{17}. X represents carbon or nitrogen. If X is nitrogen, R^{17}. The metal of the metal complex is selected from boron, beryllium, magnesium, chromium, iron, nickel, copper, zinc, and platinum.

[0037] These substituents are the same as in formula (1). Preferably, the organic fluorescent materials have a high fluorescence quantum yield to ensure increased luminance. Preferably, the following complex represented by formula (6) is used as a metal complex of the organic fluorescent materials having the pyrromethene skeleton.



(6)

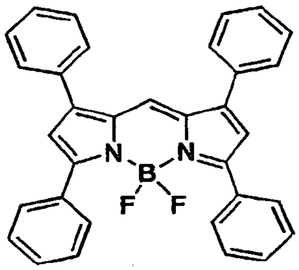
wherein at least one of R^{18} to R^{24} is an optionally substituted aromatic ring or form a fused ring with an adjacent substituent; i.e. another of the groups selected from R^{18} to R^{26}. Each other of R^{18} to R^{24} and R^{25} and R^{26} independently of each other, is a substituent selected from hydrogen, alkyl, cycloalkyl, aralkyl, alkenyl, cycloalkenyl, alkynyl, hydroxyl, mercapto, alkoxy, alkylthio, aryl ethers, aryl thioethers, aryl, heterocyclic, halogens, haloalkane, haloalkene, haloalkyne, cyano, aldehyde, carbonyl, carboxyl, esters, carbamoyl, amino, nitro, silyl, siloxanyl, and fused aromatic and alicyclic rings each formed with an adjacent substituent; i.e. another group selected from R^{18} to R^{26}. X represents carbon or nitrogen. If X is nitrogen, R^{24}.

[0038] These substituents are the same as in formula (1).

[0039] More preferably, the pyrromethene metal complex represented by formula (1) is used to prevent the degradation of fluorescence intensity in a thin-film state and thus to generate light with high luminance.

[0040] Besides the metal complex represented by formula (1), examples of metal complexes of the organic fluorescent materials having the pyrromethene skeleton include the following.

(63)



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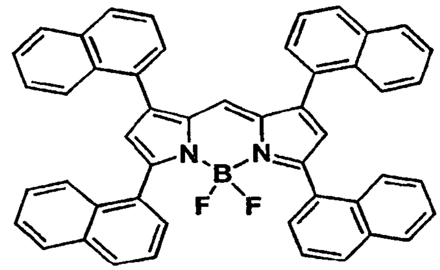

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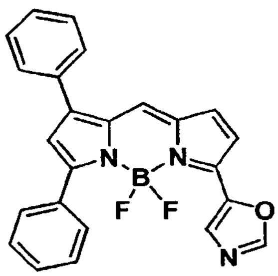

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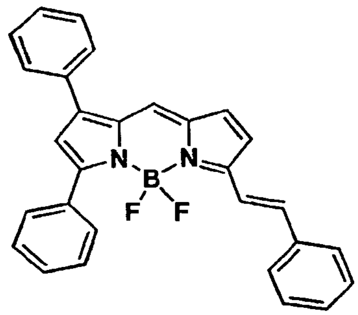

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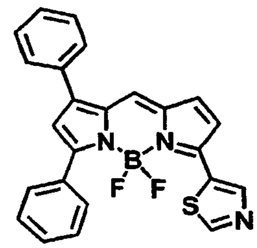

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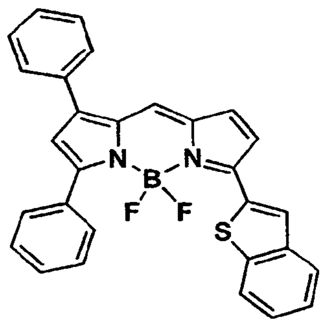

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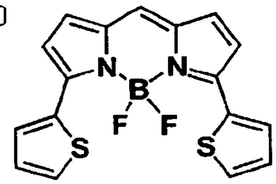

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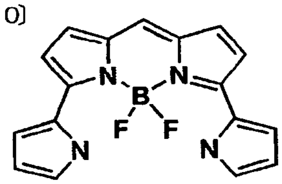

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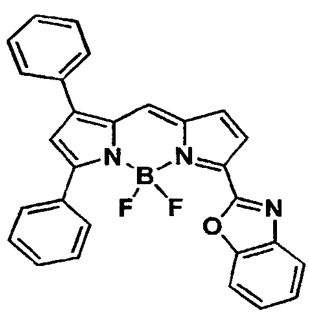

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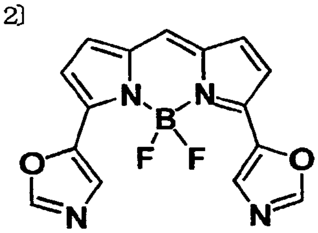

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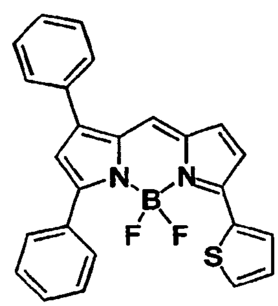

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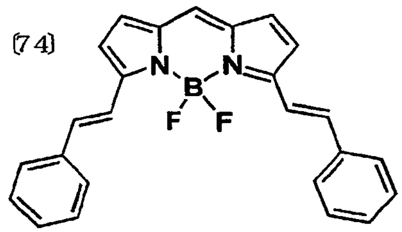

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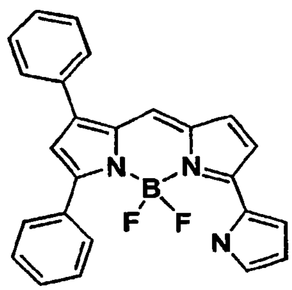

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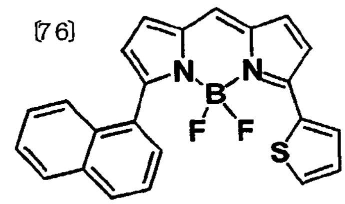

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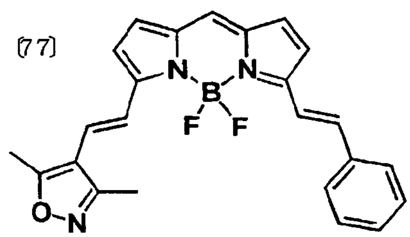

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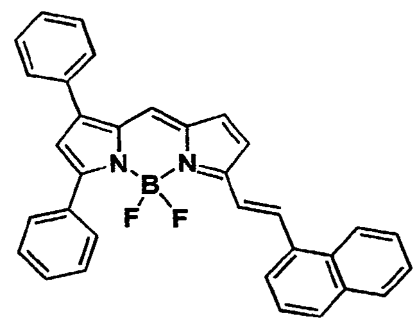

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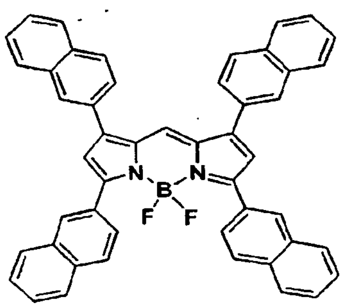

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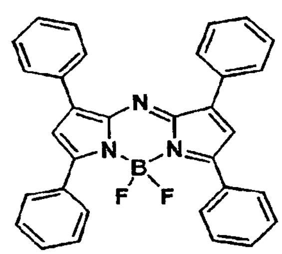

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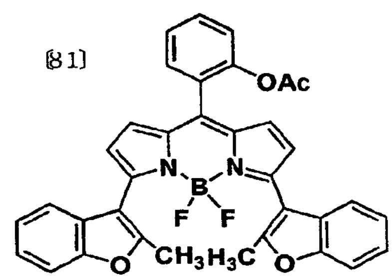

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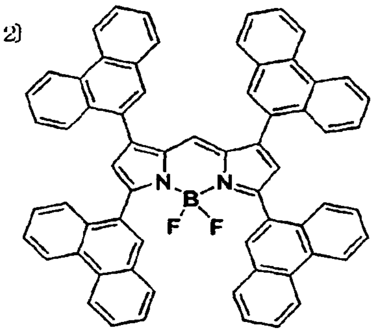

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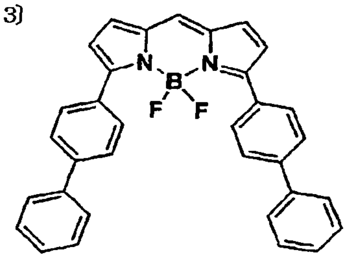

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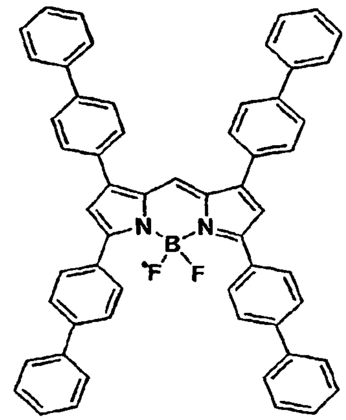

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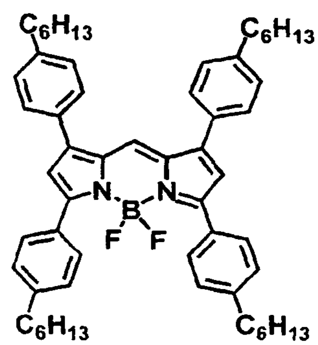

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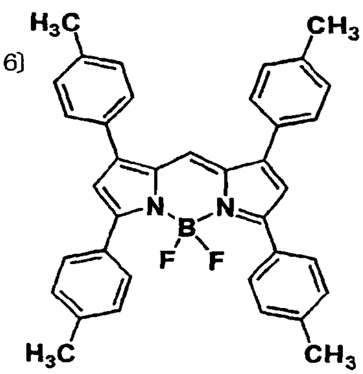

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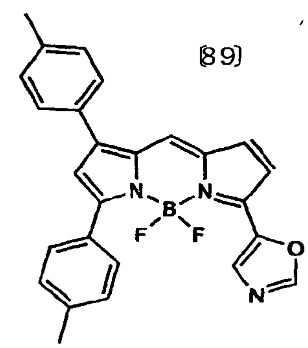

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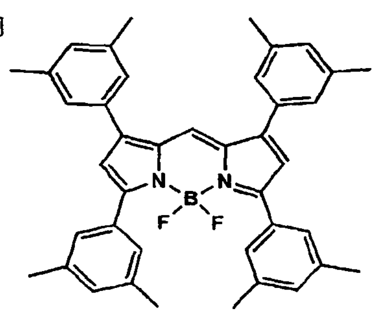

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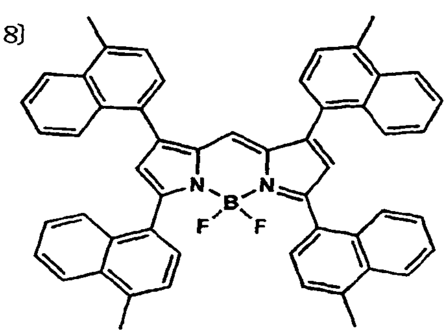

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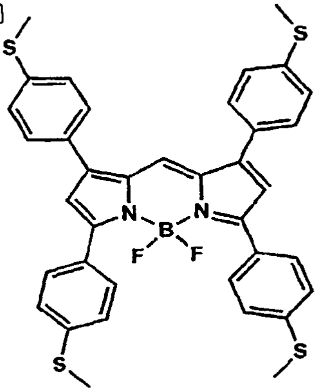

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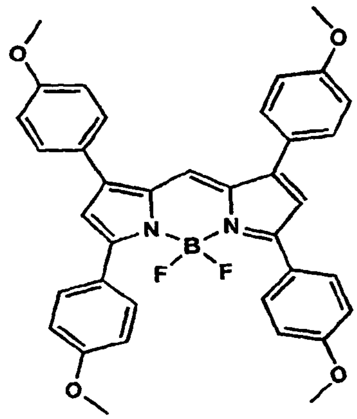

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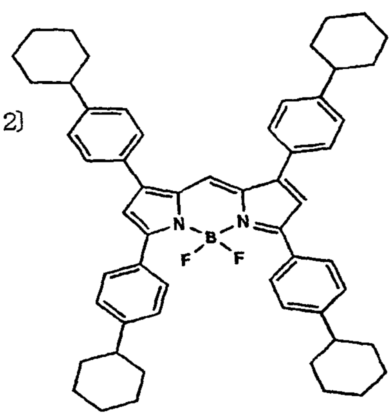

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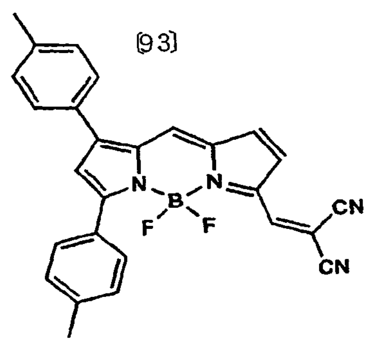

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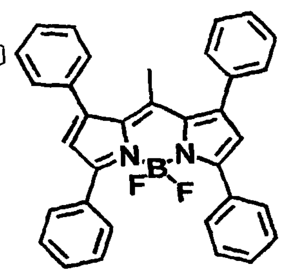

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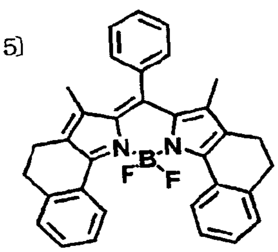

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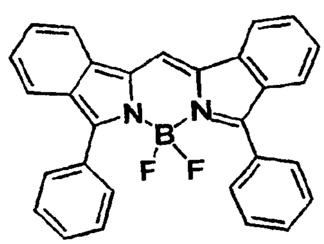

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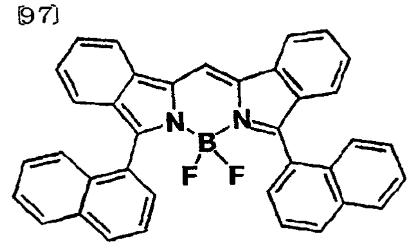

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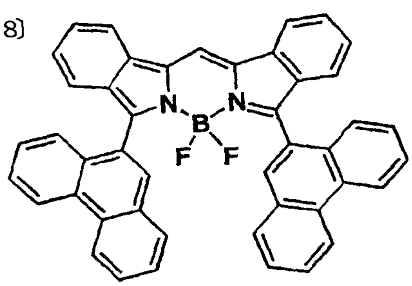

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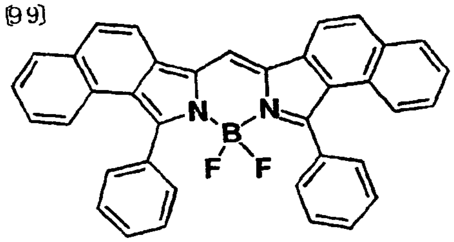

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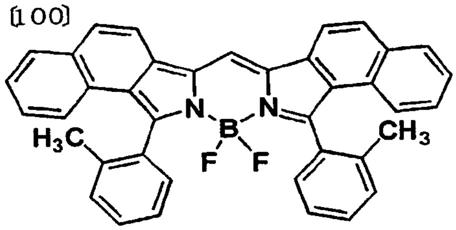

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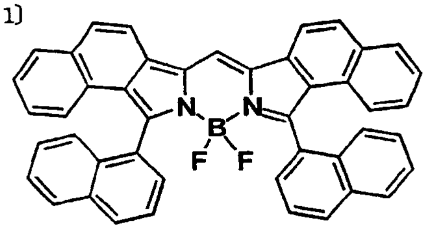

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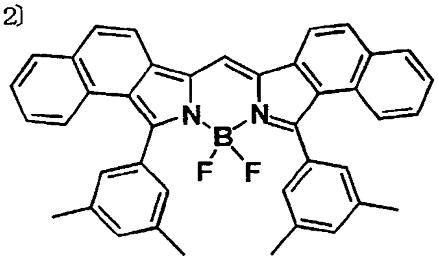

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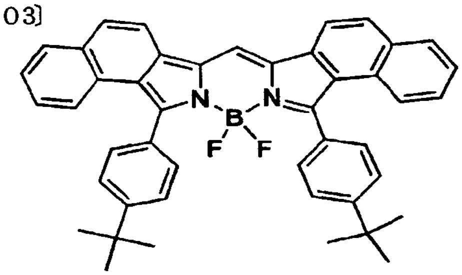

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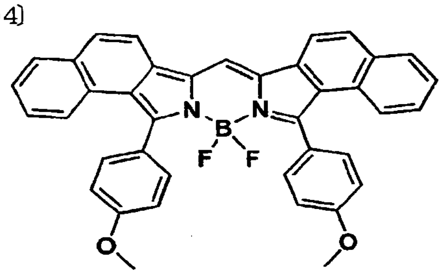

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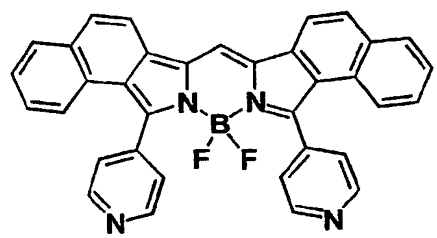

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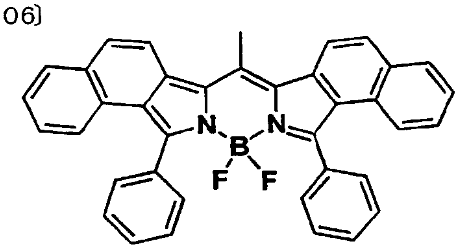

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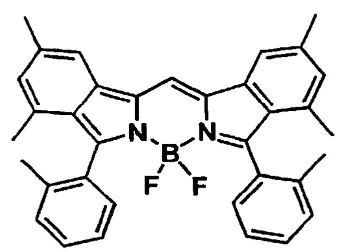


[0041] In order to transfer energy from a host material to a dopant, it is important that the fluorescence spectrum of the host material overlaps the absorption spectrum (excitation spectrum) of the dopant. The fluorescent spectrum of a host, here, is measured when the host is in a thin-film state and the absorption (excitation) spectrum and the fluorescent spectrum of the dopant are measured when the dopant is in a solution state. This is because the host is in a thin-film state and the dopant molecularly doped in the host is in almost the same state as in a solution, in the LED. If a material having excellent chromatic purity, such as the above-described substances having a pyrromethene skeleton and metal complexes thereof, is used as a dopant, the dopant exhibits a small Stokes shift (the difference between the peaks of the excitation spectrum and the fluorescent spectrum) of several to tens of nanometers. When the dopant is used for generating a red emission having a peak wavelength of 580 to 720 nm and high chromatic purity, the dopant

exhibits an absorption (excitation) spectrum in the areas of yellow, golden yellow, orange, tango and red (in the range of 540 to 720 nm). If a host material exhibits a fluorescent spectrum in a shorter wavelength band (of yellowish green, green, blue green, blue, lavender and purple) than the yellow band and thus the overlapped spectrums is small, energy transfer becomes difficult and thus light may not be emitted from the dopant. If emitted, the light would be whitened due to partial emission from the host material and thus would not become red with high chromatic purity.

[0042] Accordingly, the host material preferably has a fluorescent peak wavelength of 540 to 720 nm, so that the dopant can emit light of 580 to 720 nm with high luminance and high chromatic purity. Substances having a yellow, golden yellow, an orange, a tango and a red fluorescence correspond to such host materials. When a diketopyrrolo [3,4-c]pyrrole derivative represented by formula (1) is used as a host material, therefore, the derivative preferably has a yellow, a golden yellow, an orange, a tango or a red fluorescence.

[0043] In the case of (b), the LED material comprises a diketopyrrolo[3,4-c]pyrrole derivative represented by formula (1).

[0044] It has been known that pyrromethene metal complexes are particularly used as dopants to generate light with high luminance and that red emission is generated by introducing aromatic rings to the 1-, 3-, 5-, and 7-positions of the pyrromethene skeleton of the complex. However, the known pyrromethene compounds are liable to cause concentration quenching, and therefore cannot lead to sufficient red emission. Introducing a substituent to the 8-position of the pyrromethene skeleton decreases the concentration quenching because of the advantageous stereostructual and electronical effects of the substituent. On the other hand, if the substituent at the 8-position can rotate, the fluorescence quantum yield of the pyrromethene metal complex is degraded. In the present invention, by introducing an aryl group to the 8-position of the pyrromethene skeleton to prevent the rotation thereof, a high fluorescence quantum yield and reduced concentration quenching can be achieved. This prevention of the rotation is ensured by Ar^1 and Ar^4 of formula (1) and Ar^6 and Ar^9 of formula (2), which are aryl groups. A pyrromethene metal complex of the present invention may be used as a host, but preferably it is used as a dopant because it has a high fluorescence quantum yield and a small half band width of the emission spectrum.

[0045] Since excessive doping causes concentration quenching, 10 weight percent or less of dopant is preferably used for the host material. More preferably, 2 weight percent or less of the dopant is used for the host material. The dopant may be provided by codeposition with the host material. Alternatively, the dopant and the host material are mixed with each other and then are simultaneously deposited. The dopant may be present in part of the host material or the entirety of the host material. The dopant may be laminated as a layer or be dispersed in the host material. Since even an extremely small amount of a pyrromethene metal complex can emit light, the pyrromethene metal complex may be disposed between host layers. The dopant applied to the LED material is not limited to only one of the above-described pyrromethene metal complexes, and a plurality of pyrromethene metal complexes may be mixed. Alternatively, a pyrromethene metal complex may be mixed with at a known dopant. Examples of known dopants which can be mixed include naphthalimido derivatives such as bis(diisopropylphenyl)perylenetetracarboxylic imides; perynone derivatives; rare earth complexes such as Eu complexes of which the ligand is acetylacetone or benzoylacetone and phenanthroline; 4-(dicyanomethylene)-2-methyl-6-(p-dimethylaminostyryl)-4H-pyran and the analogues thereof; metal phthalocyanine derivatives such as magnesium phthalocyanine and aluminium chlorophthalocyanine; rhodamines; deazaflavin derivatives; coumarin derivatives; quinacridone derivatives; phenoxazines; and oxazines.

[0046] Examples of host materials include the diketopyrrolo[3,4-c]pyrrole derivatives having the specific substituents; other pyrrolopyrrole derivatives; fused aromatic ring compounds such as anthracene and pyrene; metal-chelated oxynoid compounds such as tris(8-quinolinolato)aluminium; bisstyryl derivatives such as bisstyrylanthracene derivatives and distyrylbenzene derivatives; tetraphenylbutadienes; coumarin derivatives; oxadiazoles; pyrrolopyridines; perynone derivatives; cyclopentadienes; thiadiazolopyridines; and polymers such as polyphenylene vinylenes, polyparaphenylenes, and polythiophenes.

[0047] An electron transporting material needs to efficiently transport electrons injected from the cathode between the electrodes where an electric field is applied. Preferably, the electron transporting material has a high electron injection efficiency and efficiently transports the injected electrons. Hence, the electron transporting material, preferably, has a high electron affinity and electron mobility with thermal and electrochemical stability. Preferably, the electron transporting material produces few impurities when it is prepared and used. Examples of electron transporting materials include quinolinol metal complexes such as 8-hydroxyquinoline aluminium, tropolone metal complexes, flavonol metal complexes, perylenes, perynones, naphthalenes, coumarin derivatives, oxadiazoles, aldazines, bisstyryl derivatives, pyrazines, oligopyridines such as bipyridine and terpyridine, phenanthrolines, quinolines and aromatic phosphorus oxides. These materials may be used independently or be mixed or deposited with other electron transporting materials.

[0048] In order to more efficiently generate pure red emission, the recombination of holes with electrons must occur with high probability in the emissive layer, but not in the other layers. When a diketopyrrolo[3,4-c]pyrrole derivative is used for an emissive material, preferably, the ionization potential of the electron transporting material is 5.9 eV or more. The electron transporting material needs to be stable against power distribution for long hours in order to maintain a stable red emission over time. On this account, the electron transporting material, preferably, has a molecular weight

of 400 or more, more preferably of 500 or more, and further more preferably of 600 or more. This is because many of the materials having a molecular weight less than 400 are easily affected by heat. In order to form a heat-resistant electron transporting layer, it is important to consider the glass-transition temperature of materials. A material having a higher glass-transition temperature results in a more stable amorphous layer. Preferably, the electron transporting material has a glass-transition temperature of 90°C or more, more preferably of 110°C, and still more preferably of 150°C. As such electron transporting materials, organic compounds having a structure in which a plurality of skeletons are combined with each other by means of respective interconnecting groups each having a conjugated bond, such as an aromatic hydrocarbon group, an aromatic heterocyclic group, or a combination of any of these groups (in the manner described with reference to the groups Ar^{11} and Ar^{12}), are preferably used. The skeletons of the above-described derivatives can be directly used as the skeleton of the electron transporting material. Preferably, the skeleton has at least one quinoline ring or phosphorus oxide.

[0049] The hole-blocking layer prevents holes from moving without the recombination with electrons injected from the cathode in the emissive layer where an electric field is applied. The hole-blocking layer increases the probability of the recombination, depending on materials of layers, and thus improves the luminance efficiency of the LED. For the material of the hole-blocking layer, therefore, a material is selected which has a lower energy level of the highest occupied molecular orbital than that of the hole transporting material and which rarely produce an exciplex with an adjacent layer. Since materials capable of transporting electrons can efficiently block holes, the above-described electron transporting materials are preferably used as a material of the hole-blocking layer.

[0050] The hole transporting layer, the emissive layer, the electron transporting layer, and the hole-blocking layer are formed by depositing the respective materials independently or by mixing at least two materials. Alternatively, the materials may be dispersed in a binding polymer including solvent soluble resins such as polyvinyl chloride, polycarbonate, polystyrene, poly(N-vinylcarbazole), polymethylmethacrylate, polybutylmethacrylate, polyester, polysulfone, polyphenylene oxide, polybutadiene, hydrocarbon resin, ketone resin, phenoxy resin, polysulfone, polyamide, ethyl cellulose, vinyl acetate, ABS resin, and polyurethane and hardening resins such as phenol resin, xylene resin, petroleum resin, urea resin, melamine, unsaturated polyester, alkyd resin, epoxide resin, and silicone resin.

[0051] The material capable of bringing about light emission in a light emitting device embodying the present invention is provided by, for example, resistance heating evaporation, electron beam evaporation, sputtering, molecular deposition or coating. Generally, resistance heating evaporation and electron beam evaporation are preferable in view of the performance of the LED. The thickness of the material is set between 1 to 1000 nm depending on the resistance thereof.

[0052] Mainly direct current is used as electrical energy, and pulse current or alternating current may be used. It is preferable to set a current value and voltage as low as possible with respect to power consumption and the lifetime of the device.

[0053] The LED of the present invention may be used for matrix-type displays and segment-type displays. In a matrix system, pixels of a display are arrayed in a matrix, and images including characters are displayed by aggregating the pixels. Size and shapes of the pixels depend on use. For example, square pixels having a side length of 300 μm or less are used for displaying images and characters on personal computers, monitors, and TVs. Pixels having a side length of the order of millimeters are used for large-screen displays such as instruction panels. In the case of monochrome displays, single color pixels are arrayed. In the case of color displays, red, green, and blue pixels are arrayed in typically a stripe arrangement or a delta arrangement. Matrix-type displays may be driven by a line-sequential system or an active matrix system. While the line-sequential system has a simple structure, the active matrix system can have an advantage in driving performance. These driving systems are selected according to use.

[0054] In the segment system, a pixel pattern is formed so that predetermined information is displayed and thus light is emitted at predetermined areas. Examples of segment-type displays include hour plates of digital clocks, temperature indicators, operation indicators of audiovisual apparatuses and electromagnetic cooking devices, and indicator panels of automobiles. The matrix system and the segment system may coexist in a display panel.

[0055] Embodiments of the invention will now be described in more detail with reference to the following Examples and Comparative Examples.

[0056] Compound numbers shown in Examples each designate a compound represented by the above described formula of the same number. The structures of compounds were analyzed by the following procedures.

[0057] ^{1}H-NMR analysis was performed in a heavy chloroform solution with Superconductive FTNMR EX-270 produced by JEOL.

[0058] Elemental analysis was performed with CHN Corder MT-3 produced by Yanaco, with Ion Chromatography DX320 produced by Dionex, and Sequential ICP Emission Spectrochemical system SPS4000 produced by Seiko Instruments.

[0059] Mass spectrums were measured with Mass Spectrometer JMS-DX303 produced by JEOL.

[0060] Absorption spectra and fluorescence spectra were measured in 4×10^{-6} mol/L of dichloromethane with Spectrophotometer U-3200 produced by Hitachi and Spectrofluorometer F-2500 produced by Hitachi, respectively.

Example 1

Synthesis of Compound [1]

[0061] In 30 mL of 1,2-dichloroethane, 1.3 g of 2-benzoyl-3,5-bis(4-n-hexylphenyl)pyrrole, 1 g of 2,4-bis(4-n-hexylphenyl)pyrrole, and 0.47 mL of phosphorous oxychloride were reacted with one another under reflux for 12 hours. After cooling, 3.6 mL of diisopropylethylamine and 2.6 mL of boron trifluoride diethylether complex were added and stirred for 6 hours. After 50 mL of water was added, extraction was performed with dichloromethane. The extract was concentrated and refined through a column chromatography with silica gel, thus resulting in 1 g of purplish red powder. The following is the results of ^{1}H-NMR analysis.
^{1}H-NMR ($CDCl_3$ (δ = ppm)): 0.90(t, 12H), 1.29-1.65(m, 32H), 2.39(t, 4H), 2.64(t, 4H), 6.44(t, 2H), 6.49(s, 2H), 6.60-6.63 (m, 9H), 6.83(d. 2H), 7.25(d, 4H), 7.82(d, 4H)
[0062] Elemental analysis was performed on the assumption that the composition formula of the powder was $C_{63}H_{75}N_2F_2B$. The results were as follows. Values in parentheses are theoretical values.
C: 83.5% (83.2%), H: 8.4% (8.3%), N: 3.2% (3.1%), F: 3.2% (4.2%), B: 1.2% (1.2%)
[0063] According to mass spectrometry, the main molecular ion peak of the object was m/Z = 908. Thus, the resulting purplish red powder was identified as Compound [1]. This Compound [1] exhibited the following photophysical properties.

Absorption spectrum: λmax 568 nm (solvent: dichloromethane)
Fluorescence spectrum: λmax 613 nm (solvent: dichloromethane)

[0064] Using Compound [1], and LED was then prepared. An ITO transparent conductive layer deposited on a glass substrate, having a thickness of 150 nm (produced by electron beam evaporation by Asahi Glass, 15 Ω/□) was cut into 30 mm × 40 mm and then was subjected to etching. This ITO plate was subjected to ultrasonic cleanings successively using acetone and plate cleaner Semicoclean 56 (produced by Furuuchi Chemical) for 15 minutes each, and then rinsed with ultrapure water. Subsequently, the ITO plate was subjected to ultrasonic cleaning in isopropyl alcohol for 15 minutes, then immersed in hot methanol for 15 minutes, and was followed by drying. The ITO plate was subjected to a UV-ozone treatment for one hour on the eve of the process of manufacturing the LED. Then, the ITO plate was placed in a vacuum vapor deposition apparatus and the apparatus was evacuated to a pressure of 5 × 10^{-5} Pa or below. On the ITO plate, 4,4'-bis(N-(m-tolyl)-N-phenylamino)biphenyl was deposited to a thickness of 50 nm to form a hole transporting layer by vacuum evaporation. Next, 1,4-diketo-2,5-bis(3,5-dimethylbenzyl)-3,6-bis(4-methylphenyl) pyrrolo[3,4-c]pyrrole as a host material and Compound [1] as a dopant were simultaneously deposited so as to form a layer having a thickness of 15 nm and a dopant content of 1 weight percent, and the host material was further deposited so as to have a thickness of 35 nm. Next, 0.5 nm in thickness of lithium and 150 nm in thickness of silver were deposited to form the cathode. Thus, an LED of 5 mm × 5 mm was completed. The thicknesses described above were measured by a quartz crystal oscillator thickness meter. The resulting LED generated a red emission having a peak wavelength of 618 nm and a luminance efficiency of 4.2 cd/A.

Example 2

Synthesis of Compound [2]

[0065] By the same procedure as that for Compound [1], 1.2 g of 2-benzoyl-3,5-diphenylpyrrole were reacted with 0.8 g of 2,4-diphenylpyrrole to produce 1.4 g of red powder. The results of ^{1}H-NMR analysis were as follows.
^{1}H-NMR($CDCl_3$ (δ = ppm)): 6.46(t, 2H), 6.25(s, 2H), 6.67-6.88(m, 11H), 7.43(m, 6H), 7.90(d. 4H)
[0066] Elemental analysis was performed on the assumption that the composition formula of the powder was $C_{39}H_{27}N_2F_2B$. The results were as follows. Values in parentheses are theoretical values.
C: 82.3% (81.8%), H: 4.8% (4.7%), N: 4.9% (4.9%), F: 6.6% (6.6%), B: 1.9% (2.0%)
[0067] According to mass spectrometry, the main molecular ion peak of the object was m/Z = 572. Thus, the resulting red powder was identified as Compound [2]. This Compound [2] exhibited the following photophysical properties.

Absorption spectrum: λmax 556 nm (solvent: dichloromethane)
Fluorescence spectrum: λmax 600 nm (solvent: dichloromethane)

[0068] Using Compound [2] as a dopant, an LED was then prepared by exactly the same procedure as in Example 1 other than the dopant used. This resulting LED generated a vermilion emission having a peak wavelength of 608 nm and a luminance efficiency of 2.6 cd/A.

Example 3

Synthesis of Compound [3]

[0069] By the same procedure as that for Compound [1], 0.4 g of 2-(2-methylbenzoyl)-3,5-bis(4-n-hexylphenyl)pyrrole were reacted with 0.25 g of 2,4-bis(4-n-hexylphenyl)pyrrole to produce 0.1 g of purplish red powder. The results of ^{1}H-NMR analysis were as follows.
^{1}H-NMR($CDCl_3$ (δ = ppm)): 0.88(t, 12H), 1.29-1.67(m, 32H), 2.39(t,4H), 2.63(t, 4H), 3.51(s, 3H), 6.00(d, 2H), 6.51(s, 2H), 6.63-6.73(m, 10H), 7.23(d, 4H), 7.81(d, 4H)
[0070] Elemental analysis was performed on the assumption that the composition formula of the powder was $C_{64}H_{77}N_2F_2B$. The results were as follows. Values in parentheses are theoretical values.
C: 83.3% (83.3%), H: 8.4% (8.4%), N: 3.1% (3.0%), F: 3.2% (4.1%), B: 1.2% (1.2%)
[0071] According to mass spectrometry, the main molecular ion peak of the object was m/Z = 922. Thus, the resulting purplish red powder was identified as Compound [3]. This Compound [3] exhibited the following photophysical properties.

Absorption spectrum: λmax 568 nm (solvent: dichloromethane)
Fluorescence spectrum: λmax 613 nm (solvent: dichloromethane)

[0072] Using Compound [3] as a dopant, an LED was then prepared by exactly the same procedure as in Example 1 other than the dopant used. This resulting LED generated a red emission having a peak wavelength of 618 nm and a luminance efficiency of 4.0 cd/A.

Example 4

Synthesis of Compound [4]

[0073] By the same procedure as that for Compound [1], 0.5 g of 2-(4-phenylbenzoyl)-3,5-bis(4-n-hexylphenyl)pyrrole were reacted with 0.25 g of 2,4-bis(4-n-hexylphenyl)pyrrole to produce 0.18 g of purplish red powder. The results of ^{1}H-NMR analysis were as follows.
^{1}H-NMR($CDCl_3$ (δ = ppm)): 0.84(t, 12H), 1.07-1.65(m, 32H), 2.25(t,4H), 2.64(t, 4H) , 6.53(s, 2H), 6.61-6.69(m, 11H), 6.88(d, 2H), 7.23(d, 4H), 7.24-7.37(m,5H), 7.83(d, 4H)
[0074] Elemental analysis was performed on the assumption that the composition formula of the powder was $C_{69}H_{79}N_2F_2B$. The results were as follows. Values in parentheses are theoretical values.
C: 84.3% (84.1%), H: 8.1% (8.0%), N: 2.9% (2.8%), F: 3.0% (3.9%), B: 1.2% (1.2%)
[0075] According to mass spectrometry, the main molecular ion peak of the object was m/Z = 984. Thus, the resulting purplish red powder was identified as Compound [4]. This Compound [4] exhibited the following photophysical properties.

Absorption spectrum: λmax 569 nm (solvent: dichloromethane)
Fluorescence spectrum: λmax 615 nm (solvent: dichloromethane)

[0076] Using Compound [4] as a dopant, an LED was then prepared by exactly the same procedure as in Example 1 other than the dopant used. This resulting LED generated a red emission having a peak wavelength of 618 nm and a luminance efficiency of 3.8 cd/A.

Example 5

Synthesis of Compound [5]

[0077] By the same procedure as that for Compound [1], 0.45 g of 2-(4-methoxybenzoyl)-3,5-bis(4-n-hexylphenyl) pyrrole were reacted with 0.25 g of 2,4-bis(4-n-hexylphenyl)pyrrole to produce 0.15 g of purplish red powder. The results of ^{1}H-NMR analysis were as follows.
^{1}H-NMR($CDCl_3$ (δ = ppm)): 0.91(t, 12H), 1.28-1.67(m, 32H), 2.00(s,3H), 2.38(t, 4H), 2.63(t, 4H), 6.21(d, 1H), 6.43(s, 2H), 6.46(d, 2H), 6.63(m, 8H), 6.80(d, 1H), 7.25(d, 4H), 7.82(d, 4H)
[0078] Elemental analysis was performed on the assumption that the composition formula of the powder was $C_{64}H_{77}N_2OF_2B$. The results were as follows. Values in parentheses are theoretical values.
C: 82.1% (81.9%), H: 8.3% (8.2%), N: 3.1% (3.0%), O: 1.8% (1.7%), F: 3.0% (4.0%), B: 1.2% (1.2%)
[0079] According to mass spectrometry, the main molecular ion peak of the object was m/Z = 938. Thus, the resulting purplish red powder was identified as Compound [5]. This Compound [5] exhibited the following photophysical properties.

Absorption spectrum: λmax 566 nm (solvent: dichloromethane)

Fluorescence spectrum: λmax 611 nm (solvent: dichloromethane)

[0080] Using Compound [5] as a dopant, an LED was then prepared by exactly the same procedure as in Example 1 other than the dopant used. This resulting LED generated a red emission having a peak wavelength of 615 nm and a luminance efficiency of 4.0 cd/A.

Example 6

Synthesis of Compound [6]

[0081] By the same procedure as that for Compound [1], 0.4 g of 2-(4-cyanobenzoyl)-3,5-bis(4-n-hexylphenyl)pyrrole were reacted with 0.25 g of 2,4-bis(4-n-hexylphenyl)pyrrole to produce 0.3 g of auburn powder. The results of ^{1}H-NMR analysis were as follows.

^{1}H-NMR(CDCl$_3$ (δ = ppm)): 0.91(t, 12H), 1.33-1.65(m, 32H), 2.44(t, 4H), 2.64(t, 4H), 6.52(s, 2H), 6.59(d, 2H), 6.70-6.75 (m, 8H), 6.93(d, 2H), 7.25(d, 4H), 7.83(d, 4H)

[0082] Elemental analysis was performed on the assumption that the composition formula of the powder was $C_{64}H_{74}N_3F_2B$. The results were as follows. Values in parentheses are theoretical values.

C: 82.6% (82.3%), H: 7.9% (7.9%), N: 4.6% (4.5%), F: 3.3% (4.1%), B: 1.2% (1.2%)

[0083] According to mass spectrometry, the main molecular ion peak of the object was m/Z =933. Thus, the resulting auburn powder was identified as Compound [6]. This Compound [6] exhibited the following photophysical properties.

Absorption spectrum: λmax 576 nm (solvent: dichloromethane)

Fluorescence spectrum: λmax 626 nm (solvent: dichloromethane)

Example 7

Synthesis of Compound [7]

[0084] By the same procedure as that Compound [1], 0.5 g of 2-(1-naphthoyl)-3,5-bis(4-n-hexylphenyl)pyrrole were reacted with 0.25 g of 2,4-bis(4-n-hexylphenyl)pyrrole to produce 0.2 g of purple powder. The results of ^{1}H-NMR analysis were as follows.

^{1}H-NMR(CDCl$_3$ (δ = ppm)): 0.93(t, 12H), 1.25-1.65(m, 32H), 2.21(t, 4H), 2.64(t, 4H), 6.27(m, 8H), 6.40(s, 2H), 6.64(t, 1H), 7.00(dd, 2H), 7.24(d, 4H), 7.24-7.34(m, 3H), 7.80-7.87(m, 5H)

[0085] Elemental analysis was performed on the assumption that the composition formula of the powder was $C_{67}H_{77}N_2F_2B$. The results were as follows. Values in parentheses are theoretical values.

C: 84.3% (83.9%), H: 8.1% (8.0%), N: 2.9% (2.9%), F: 3.1% (4.0%), B: 1.1% (1.2%)

[0086] According to mass spectrometry, the main molecular ion peak of the object was m/Z =958. Thus, the resulting purple powder was identified as Compound [7]. This Compound [7] exhibited the following photophysical properties.

Absorption spectrum: λmax 571 nm (solvent: dichloromethane)

Fluorescence spectrum: λmax 616 nm (solvent: dichloromethane)

[0087] Using Compound [7] as a dopant, an LED was then prepared by exactly the same procedure as in Example 1 other than the dopant used. This resulting LED generated a red emission having a peak wavelength of 619 nm and a luminance efficiency of 4.2 cd/A.

Example 8

Synthesis of Compound [8]

[0088] By the same procedure as that for Compound [1], 0.4 g of 2- benzoyl-3,5-bis(4-methoxyphenyl)pyrrole were reacted with 0.25 g of 2,4-bis(4-methoxyphenyl)pyrrole to produce 0.2 g of blue-purple powder. The results of ^{1}H-NMR analysis were as follows.

^{1}H-NMR(CDCl$_3$ (δ = ppm)): 3.67(s, 3H), 3.86(s, 3H), 6.38(d, 2H), 6.47(s, 2H), 6.54(t, 2H), 6.64-6.75(m, 5H), 6.85(d, 2H), 6.96(d, 4H), 7.89(d, 4H)

[0089] Elemental analysis was performed on the assumption that the composition formula of the powder was $C_{43}H_{35}N_2O_4F_2B$. The results were as follows. Values in parentheses are theoretical values.

C: 75.0% (74.6%), H: 5.2% (5.1%), N: 4.2% (4.0%), O: 9.3% (9.2%), F: 4.4% (5.5%), B: 1.6% (1.6%)

[0090] According to mass spectrometry, the main molecular ion peak of the object was m/Z =692. Thus, the resulting blue-purple powder was identified as Compound [8]. This Compound [8] exhibited the following photophysical properties.

Absorption spectrum: λmax 584 nm (solvent: dichloromethane)

Fluorescence spectrum: λmax 632 nm (solvent: dichloromethane)

[0091] Using Compound [8] as a dopant, an LED was then prepared by exactly the same procedure as in Example 1 other than the dopant used. This resulting LED generated a red emission having a peak wavelength of 641 nm and a luminance efficiency of 2.7 cd/A.

Example 9

Synthesis of Compound [9]

[0092] By the same procedure as that for Compound [1], 0.35 g of 2- benzoyl-3,5-bis(4-n-amyloxyphenyl)pyrrole were reacted with 0.25 g of 2,4-bis(4-n-amyloxyphenyl)pyrrole to produce 0.1 g of blue-purple powder. The results of ^{1}H-NMR analysis were as follows.
^{1}H-NMR($CDCl_3$ (δ = ppm)): 0.94(t, 12H), 1.38-1.41(m, 16H), 1.68-1.83(m, 8H), 3.80(t, 4H), 4.00(t, 4H), 6.36(d, 2H), 6.46(s, 2H), 6.53(t, 2H), 6.62-6.73(m, 5H), 6.85(d, 2H), 6.94(d, 4H), 7.86(d, 4H)

[0093] Elemental analysis was performed on the assumption that the composition formula of the powder was $C_{59}H_{67}N_2O_4F_2B$. The results were as follows. Values in parentheses are theoretical values.
C: 77.5% (77.3%), H: 7.5% (7.5%), N: 3.2% (3.1%), O: 7.1% (7.0%), F: 3.1% (4.1%), B: 1.2% (1.2%)

[0094] According to mass spectrometry, the main molecular ion peak of the object was m/Z = 916. Thus, the resulting blue-purple powder was identified as Compound [9]. This Compound [9] exhibited the following photophysical properties.

Absorption spectrum: λmax 587 nm (solvent: dichloromethane)
Fluorescence spectrum: λmax 636 nm (solvent: dichloromethane)

Example 10

Synthesis of Compound [10]

[0095] By the same procedure as that for Compound [1], 0.6 g of 2-(1-naphtoyl)-3,5-bis(4-methylphenyl)pyrrole were reacted with 0.25 g of 2,4-bis(4-methylphenyl)pyrrole to produce 0.55 g of purple powder. The results of ^{1}H-NMR analysis were as follows.
^{1}H-NMR ($CDCl_3$ (δ = ppm)): 2.00(s, 6H), 2.40(s, 6H), 6.26(m, 8H), 6.39(s, 2H), 6.65(t, 1H), 7.00(d, 1H), 7.12(d, 1H), 7.24(d, 4H), 7.24-7.33(m, 3H), 7.77-7.86(m, 5H)

[0096] Elemental analysis was performed on the assumption that the composition formula of the powder was $C_{47}H_{37}N_2F_2B$. The results were as follows. Values in parentheses are theoretical values.
C: 83.5% (83.2%), H: 5.6% (5.5%), N: 4.3% (4.1%), F: 4.8% (5.6%), B: 1.5% (1.6%)

[0097] According to mass spectrometry, the main molecular ion peak of the object was m/Z = 678. Thus, the resulting purple powder was identified as Compound [10]. This Compound [10] exhibited the following photophysical properties.

Absorption spectrum: λmax 575 nm (solvent: dichloromethane)
Fluorescence spectrum: λmax 613 nm (solvent: dichloromethane)

[0098] Using Compound [10] as a dopant, an LED was then prepared by exactly the same procedure as in Example 1 other than the dopant used. This resulting LED generated a red emission having a peak wavelength of 620 nm and a luminance efficiency of 3.0 cd/A.

Example 11

Synthesis of Compound [11]

[0099] By the same procedure as that for Compound [1], 0.35 g of 2-benzoyl-3,5-bis(4-(2,4-dimethylphenyl)phenyl) pyrrole were reacted with 0.25 g of 2,4-bis(4-(2,4-dimethylphenyl)phenyl)pyrrole to produce 0.15 g of purple powder. The results of ^{1}H-NMR analysis were as follows.
^{1}H-NMR ($CDCl_3$ (δ = ppm)): 2.18(s, 6H), 2.32(s, 6H), 2.36(ss,12H), 6.67(s, 2H), 6.81(d,8H), 6.94-7.07(m, 11H), 7.11 (d, 2H), 7.43(d, 4H), 8.01(d, 4H)

[0100] Elemental analysis was performed on the assumption that the composition formula of the powder was $C_{71}H_{59}N_2F_2B$. The results were as follows. Values in parentheses are theoretical values.
C: 86.4% (86.2%), H: 6.0% (6.0%), N: 2.9% (2.8%), F: 3.0% (3.9%), B: 1.2% (1.1%)

[0101] According to mass spectrometry, the main molecular ion peak of the object was m/Z = 988. Thus, the resulting purple powder was identified as Compound [11]. This Compound [11] exhibited the following photophysical properties.

Absorption spectrum: λmax 576 nm (solvent: dichloromethane)

Fluorescence spectrum: λmax 626 nm (solvent: dichloromethane)

Example 12

Synthesis of Compound [12]

[0102] By the same procedure as that for Compound [1], 0.4 g of 2-(1-naphthoyl)-3,5-bis(4-methylphenyl)pyrrole were reacted with 0.25 g of 2,4-bis(4-methoxyphenyl)pyrrole to produce 0.1 g of purple powder. The results of ^{1}H-NMR analysis were as follows.
^{1}H-NMR ($CDCl_3$ (δ = ppm)): 1.97(s, 3H), 2.40(s, 3H), 3.54(s, 3H), 3.86(s, 3H), 5.99(d, 2H), 6.25(s, 4H), 6.30-6.39(m, 8H), 6.69(t, 1H), 6.97(d, 3H), 7.14(d, 1H), 7.26(d, 2H), 7.26-7.37(m, 3H), 7.78-7.95(m, 5H)
[0103] Elemental analysis was performed on the assumption that the composition formula of the powder was $C_{47}H_{37}N_2O_2F_2B$. The results were as follows. Values in parentheses are theoretical values.
C: 79.6% (79.4%), H: 5.1% (5.2%), N: 4.0% (3.9%), O: 4.6% (4.5%), F: 4.6% (5.4%), B: 1.6% (1.6%)
[0104] According to mass spectrometry, the main molecular ion peak of the object was m/Z = 710. Thus, the resulting purple powder was identified as Compound [12]. This Compound [12] exhibited the following photophysical properties.
Absorption spectrum: λmax 577 nm (solvent: dichloromethane)
Fluorescence spectrum: λmax 624 nm (solvent: dichloromethane)
[0105] Using Compound [12] as a dopant, an LED was then prepared by exactly the same procedure as in Example 1 other than the dopant used. This resulting LED generated a red emission having a peak wavelength of 628 nm and a luminance efficiency of 2.9 cd/A.

Example 13

Synthesis of Compound [53]

[0106] By the same procedure as that for Compound [1], 0.4 g of 2-benzoyl-3,5-bis(4-n-butylphenyl)pyrrole were reacted with 0.25 g of 2,4-bis(4-n-butylphenyl)pyrrole to produce 0.27 g of red powder. The results of ^{1}H-NMR analysis were as follows.
^{1}H-NMR ($CDCl_3$ (δ = ppm)): 1.97(s, 3H), 2.40(s, 3H), 3.54(s, 3H), 3.86(s, 3H), 5.99(d, 2H), 6.25(s, 4H), 6.30-6.39(m, 8H), 6.69(t, 1H), 6.97(d, 3H), 7.14(d, 1H), 7.26(d, 2H), 7.26-7.37(m, 3H), 7.78-7.95(m, 5H)
[0107] Elemental analysis was performed on the assumption that the composition formula of the powder was $C_{55}H_{59}N_2F_2B$. The results were as follows. Values in parentheses are theoretical values.
C: 83.1% (82.9%), H: 7.5% (7.4%), N: 3.6% (3.5%), F: 4.0% (4.8%), B: 1.3% (1.4%)
[0108] According to mass spectrometry, the main molecular ion peak of the object was m/Z = 796. Thus, the resulting red powder was identified as Compound [53]. This Compound [53] exhibited the following photophysical properties.
Absorption spectrum: λmax 569 nm (solvent: dichloromethane)
Fluorescence spectrum: λmax 611 nm (solvent: dichloromethane)
[0109] Using Compound [53] as a dopant, an LED was then prepared by exactly the same procedure as in Example 1 other than the dopant used. This resulting LED generated a red emission having a peak wavelength of 617 nm and a luminance efficiency of 5.0 cd/A.

Example 14

Synthesis of Compound [59]

[0110] In 30 mL of absolute tetrahydrofuran, 0.5 g of compound [10] was dissolved. Subsequently, 1.88 mL of phenylmagnesium bromide (1.0 mol/L in tetrahydrofuran) was dropped into the tetrahydrofuran solution at 20°C and then was reacted at 60°C for 9 hours. After cooling, 50 mL of water was added and then extraction was performed with dichloromethane. The extract was concentrated and refined through a column chromatography with silica gel, thus resulting in 0.32 g of purplish red powder. The following were the results of ^{1}H-NMR analysis.
^{1}H-NMR ($CDCl_3$ (δ = ppm)): 1.97(s, 3H), 2.40(s, 3H), 3.54(s, 3H), 3.86(s, 3H), 5.99(d, 2H), 6.25(s, 4H), 6.30-6.39(m, 8H), 6.69(t, 1H), 6.97(d, 3H), 7.14(d, 1H), 7.26(d, 2H), 7.26-7.37(m, 3H), 7.78-7.95(m, 5H)
[0111] Elemental analysis was performed on the assumption that the composition formula of the powder was $C_{59}H_{47}N_2B$. The results were as follows. Values in parentheses are theoretical values.
C: 89.3% (89.2%), H: 6.0% (5.9%), N: 3.5% (3.5%), B: 1.2% (1.4%)
[0112] According to mass spectrometry, the main molecular ion peak of the object was m/Z = 794. Thus, the resulting purplish red powder was identified as Compound [59]. This Compound [59] exhibited the following photophysical prop-

erties.

Absorption spectrum: λmax 568 nm (solvent: dichloromethane)

Fluorescence spectrum: λmax 613 nm (solvent: dichloromethane)

[0113] Using Compound [59] as a dopant, an LED was then prepared by exactly the same procedure as in Example 1 other than the dopant used. This resulting LED generated a red emission having a peak wavelength of 616 nm and a luminance efficiency of 3.8 cd/A.

Example 15

[0114] For preparing an LED, the same procedure as that in Example 1 was adopted until the hole transporting layer was deposited, and then the compound [53] was deposited to a thickness of 50 nm. Next, 0.5 nm in thickness of lithium and 150 nm in thickness of silver were successively deposited to form the cathode. Thus, an LED of 5 mm × 5 mm was completed. This resulting LED generated a red emission having a peak wavelength of 622 nm and a luminance efficiency of 2.5 cd/A.

Example 16

[0115] Using Compound [63] as a dopant, an LED was then prepared by exactly the same procedure as in Example 1 other than the dopant used. This resulting LED generated a red emission having a peak wavelength of 609 nm and a luminance efficiency of 1.6 cd/A.

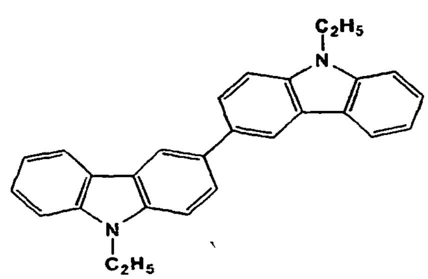
[0116] Using Compound [85] as dopant, an LED was then prepared by exactly the same procedure as in Example 1 other than the dopant used. This resulting LED generated a red emission having a peak wavelength of 628 nm and a luminance efficiency of 1.1 cd/A.

Example 18

[0117] For preparing an LED, the same procedure as in Example 1 was adopted until the hole transporting layer was deposited. Then, 1,4-diketo-2,5-bis(3,5-dimethylbenzyl)-3,6-bis(4-methylphenyl)pyrrolo[3,4-c]pyrrole as a host material and 9-diethylamino-5H-benzo(a)phenoxazine-5-one (the fluorescent peak wavelength was 610 nm in dichloromethane) as a dopant were simultaneously deposited so as to form an emissive layer having a thickness of 25 nm and a dopant content of 0.5 weight percent. Next, 2,9-dimethyl-4,7-diphenyl-1,10-phenanthroline (BCP) was deposited to form the electron transporting layer having a thickness of 25 nm. Finally, 0.5 nm in thickness of lithium and 150 nm in thickness of silver were deposited to form the cathode and thus an LED of 5 mm × 5 mm was completed. This resulting LED generated a red emission having an emission peak wavelength of 609 nm and a spectrum half band width of 71 nm depending on the dopant. The red emission exhibited a luminance of 3000 cd/m^2 under an applied voltage of 16 V.

Examples 19 to 25 and 28 to 29 and Comparative Example 1

[0118] LEDs were prepared by the same procedure as in Example 18 except that compounds shown in Table 1 were used as a hole transporting material, a host material, dopant, and a cathode material. The results are shown in Table 1. HTM1 used in Example 25 is the following compound:



HTM1

Table 1

	Hole transporting layer	Emissive layer			Electron transporting layer	Cathode	Emission peak wavelength (nm)	Spectrum half band width (nm)	Applied voltage (V)	Luminance (cd/m²)
		Host material	Dopant	Fluorescent peak wavelength In CH2Cl2nm)						
Example 18	4,4'-bis(N-(m-tolyl)-N-phenylamino)biphenyl	1,4-diketo-2,5-bis(3,5-dimethylbenzyl)-3,6-bis(4-methylphenyl)pyrrolo[3,4-c]pyrrole	9-diethylamino-5H-benzo(a) phenoxazine-5-one	610	BCP	Li 0.5 nm Ag 150 nm	609	71	16	3000
Example 19	ditto	ditto	3-ethyl-2-[3-(3-ethyl-2-benzothiazolinylidene)-1-propenyl]benzothiazolium iodide	596	BCP	Li 0.5 nm Ag 150 nm	602	45	16	1200
Example 20	ditto	ditto	4-(dicyanomethylene)-2-methyl-6-(1,1,7,7-tetramethyljulolidyl- 9-enyl)-4H-pyran	625	BCP	Li 0.5 nm Ag 150 nm	609	88	16	1500
Example 21	ditto	ditto	Compound [99]	629	BCP	Li 0.5 nm Ag 150 nm	636	33	12	10000
Example 22	ditto	ditto	Compound [63]	605	BCP	Li 0.5 nm Ag 150 nm	617	42	16	3000
Comparative Example 1	ditto	1,4-diketo-2,5-dimethyl-3,6-diphenylpirrolo[3,4-c]pyrrole	Compound [63]	605	BCP	Li 0.5 nm Ag 150 nm	609	52	16	900
Example 23	ditto	1,4-diketo-2,5-bis(3,5-dimethylbenzyl)-3,6-bis(4-methylphenyl)pyrrolo[3,4-c]pyrrole	Compound [66]	625	BCP	Li 0.5 nm Ag 150 nm	632	40	19	3200
Example 24	ditto	ditto	Compound [65]	606	BCP	Li 0.5 nm Ag 150 nm	612	40	17	4200
Example 25	HTM1	ditto	Compound [65]	606	BCP	Li 0.5 nm Ag 150 nm	612	40	14	7000
Example 28	4,4'-bis(N-(m-tolyl)-N-phenylamino)biphenyl	ditto	Compound [73]	630	BCP	Li 0.5 nm Ag 150 nm	629	38	15	3600
Example 29	ditto	ditto	Compound [69]	641	BCP	Li 0.5 nm Ag 150 nm	645	32	17	2900

Example 26

[0119] An LED was prepared by the same procedure as in Example 24 except that a layer of copper phthalocyanine (CuPc) 10 nm in thickness as a first hole transporting layer and HTM1 as a second hole transporting layer were successively deposited. This resulting LED generated a red emission having an emission peak wavelength of 612 nm and a spectrum half band width of 40 nm provided by the compound [65]. The red emission exhibited a luminance of 6400 cd/m^2 under an applied voltage of 14 V.

Example 27

[0120] For preparing an LED, the compound [100], which has a fluorescent peak wavelength of 619 nm in dichloromethane solution, was used as a dopant to form the emissive layer. Subsequently, 20 nm in thickness of the host material used in the emissive layer and 5 nm in thickness of BCP were successively used to form the electron transporting layer. Aluminium was used for the cathode instead of silver. Other processes were the same as in Example 18. This resulting LED generated a red emission having an emission peak wavelength of 629 nm and a spectrum half band width of 28 nm provided by the compound [100]. The red emission exhibited a luminance of 7500 cd/m^2 under an applied voltage of 14 V.

Examples 30 to 47

[0121] LEDs were prepared by the same procedure as in Example 27 except that compounds shown in Tables 2 and 3 were used as a hole transporting material, a host material, and a dopant. The results are shown in Tables 2 and 3.

Table 2

	Hole transporting layer	Emissive layer			Electron transporting layer		Cathode	Emission peak wavelength (nm)	Spectrum half band width (nm)	Applied voltage (V)	Luminance (cd/m^2)
		Host material	Dopant	Fluorescent peak wavelength in CH2Cl2 (nm)							
Example 27	4,4'-bis(N-(m-tolyl)-N-phenylamino)biphenyl	1,4-diketo-2,5-bis(3,5-dimethylbenzyl)-3,6-bis(4-methylphenyl)pyrrolo[3,4-c]pyrrole	Compound [100]	619	Host material 20 nm	BCP 5 nm	Li 0.5 nm Al 150 nm	629	28	14	7500
Example 30	ditto	ditto	Compound [86]	617	Host material 20 nm	BCP 5 nm	Ditto	628	43	13	9500
Example 31	ditto	1,4-diketo-2,5-bis(3-methylbenzyl)-3,6-bis(4-biphenyl)pyrrolo[3,4-c]pyrrole	Compound [99]	629	Host material 20 nm	BCP 5 nm	ditto	639	28	14	1700
Example 32	ditto	ditto	Compound [100]	619	Host material 20 nm	BCP 5 nm	ditto	633	28	13	5300
Example 33	ditto	1,4-diketo-2,5-bis(2-methylbenzyl)-3,6-bis(2-naphthyl)pyrrolo[3,4-c]pyrrole	Compound [99]	629	Host material 20 nm	BCP 5 nm	ditto	642	33	14	2700
Example 34	ditto	1,4-diketo-2,5-bis(3,5-dimethylbenzyl)-3,6-bis(2-(6-methoxynaphthyl)) pyrrolo[3,4-c]pyrrole	Compound [99]	629	Host material 20 nm	BCP 5 nm	ditto	637	33	14	1000
Example 35	ditto	1,4-diketo-2,5-bis(3,5-di-tert-butylbenzyl)-3,6-bis(2-naphthyl)pyrrolo[3,4-c]pyrrole	Compound [99]	629	Host material 20 nm	BCP 5 nm	ditto	637	33	16	3500
Example 36	ditto	1,4-diketo-2,5-bis(3,5-di-tert-butylbenzyl)-3,6-bis(4-methylphenyl)pyrrolo[3,4-c]pyrrole	Compound [99]	629	Host material 20 nm	BCP 5 nm	ditto	631	33	15	3100
Example 37	ditto	Ditto	Compound [86]	617	Host material 20 nm	BCP 5 nm	ditto	624	43	14	4400

Table 3

	Hole transporting layer	Emissive layer			Electron transporting layer		Cathode	Emission peak wavelength (nm)	Spectrum half band width (nm)	Applied voltage (V)	Luminance (cd/m^2)
		Host material	Dopant	Fluorescent peak wavelength in CH2Cl2nm)							
Example 38	4,4'-bis(N-(m-tolyl)-N-phenylamino)biphenyl	1,4-diketo-2,5-bis(3,5-di-tert-butylbenzyl)-3,6-bis(4-biphenyl)pyrrolo[3,4-c]pyrrole	Compound [99]	629	Host material 20 nm	BCP 5 nm	Li 0.5 nm Al 150 nm	638	33	15	5200
Example 39	ditto	Ditto	Compound [100]	619	Host material 20 nm	BCP 5 nm	ditto	628	28	16	7500
Example 40	ditto	Ditto	Compound [73]	630	Host material 20 nm	BCP 5 nm	ditto	628	38	18	2500
Example 41	ditto	Ditto	Compound [69]	630	Host material 20 nm	BCP 5 nm	ditto	645	32	16	1800
Example 42	ditto	1,4-diketo-2,5-bis(3,5-di-tert-butylbenzyl)-3,6-bis(3-methylphenyl)pyrrolo[3,4-c]pyrrole	Compound [99]	629	Host material 20 nm	BCP 5 nm	ditto	631	33	15	2300
Example 43	ditto	1,4-diketo-2,5-bis(3,5-di-tert-butylbenzyl)-3,6-bis(3-methoxyphenyl)pyrrolo[3,4-c]pyrrole	Compound [99]	629	Host material 20 nm	BCP 5 nm	ditto	640	33	15	3400
Example 44	4,4'-bis(N-(m-tolyl)-N-phenylamino)biphenyl	1,4-diketo-2,5-bis(3,5-di-tert-butylbenzyl)-3,6-bis(4-chlorophenyl)pyrrolo[3,4-c]pyrrole	Compound [99]	629	Host material 20 nm	BCP 5 nm	ditto	640	33	15	4200
Example 45	ditto	1,4-diketo-2,5-bis(3,5-di-tert-butylbenzyl)-3,6-bis(4-trans-stilbene)pyrrolo[3,4-c]pyrrole	Compound [99]	629	Host material 20 nm	BCP 5 nm	ditto	637	33	17	1900
Example 46		Ditto	Compound [73]	630	Host material 20 nm	BCP 5 nm	ditto	630	38	22	1200
Example 47	ditto	Ditto	Compound [69]	641	Host material 20 nm	BCP 5 nm	ditto	648	32	18	1100

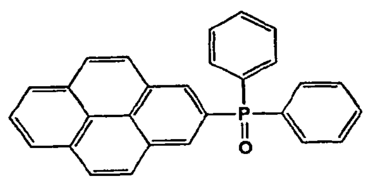
Example 48

[0122] For preparing an LED, 1,4-diketo-2,5-bis(2-phenybenzyl)-3,6-bis(4-methylphenyl)pyrrolo[3,4-c]pyrrole was used as a host material. Other process steps were the same as in Example 21. This resulting LED generated a red emission having an emission peak wavelength of 639 nm and a spectrum half band width of 33 nm provided by the compound [99]. The red emission exhibited a luminance of 2000 cd/m^2 under an applied voltage of 13 V.

Example 49

[0123] For preparing an LED, 1,4-diketo-2,5-bis(3,5-dimethylbenzyl)-3,6-bis(4-ethylphenyl)pyrrolo[3,4-c]pyrrole and the compound [1], which had a fluorescent peak wavelength of 613 nm in dichloromethane solution, were used as a host material and a dopant, respectively. Other process steps were the same as in Example 28. This resulting LED generated a red emission having an emission peak wavelength of 618 nm and a spectrum half band width of 48 nm provided by the compound [1]. The red emission exhibited a luminance of 8000 cd/m^2 under an applied voltage of 14 V.

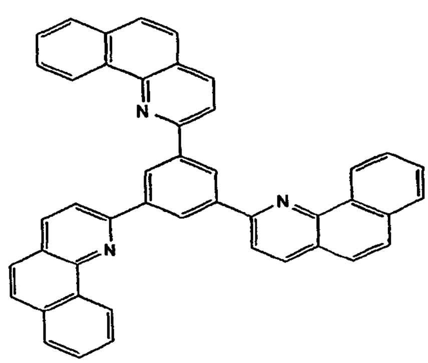
[0124] First, CuPc was deposited to a thickness of 10 nm to form a first hole transporting layer, and then N,N'-diphenyl-N-N'-di(naphthalene-1-yl)-1,1'-dipheny-4,4'-diamine(α-NPD) was deposited to a thickness of 50 nm to form a second hole transporting layer. The electron transporting layer was formed of ETM1. Other process steps were the same as in Example 49. ETM1 has an ionization potential of 5.99 eV (measured with Atmospheric Ultra-violet Photo-electron Spectrometer produced by Riken Keiki) and a molecular weight of 401. This resulting LED generated a red emission having an emission peak wavelength of 618 nm and a spectrum half band width of 48 nm provided by the compound [1]. The red emission exhibited a luminance of 9000 cd/m^2 under an applied voltage of 15 V.



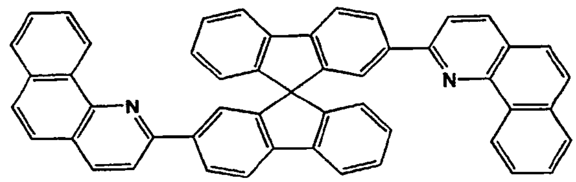
ETM1

Examples 51 to 53

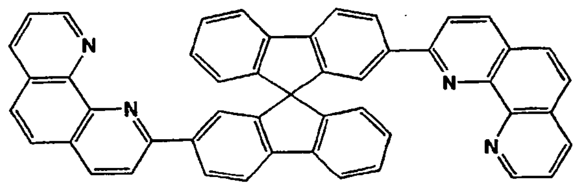
[0125] LEDs were prepared by the same procedure as in Example 49 except that the compounds shown in Table 4 were used for the electron transporting layer. The results are shown in Table 4. ETM2, ETM3, and ETM4 shown in Table 4 are as follows:



ETM2



ETM 3



ETM 4

Table 4

	Hole transporting layer	Emissive layer			Electron transporting layer				Cathode	Emission peak wavelength (nm)	Spectrum half band width (nm)	Applied voltage (V)	Luminance (cd/m^2)
		Host material	Dopant	Fluorescent peak wavelength in CH2Cl2nm)		Ionization potential (eV)	Molecular weight	Tg (°C)					
Example 49	4,4'-bis(N-(m-tolyl)-N-phenylamino)biphenyl	1,4-diketo-2,5-bis(3,5-dimethylbenzyl)-3,6-bis(4-ethylphenyl)pyrrolo[3,4-c]pyrrole	Compound [1]	613	BCP	5.85	360	≤ 77	Li 0.5 nm Al 150 nm	618	48	14	8000
Example 51	ditto	ditto	ditto	613	ETM2	5.97	609	112	ditto	618	48	15	8000
Example 52	ditto	ditto	ditto	613	ETM3	6.07	670	165	ditto	618	48	15	10000
Example 53	ditto	ditto	ditto	613	ETM4	6.07	672	219	ditto	618	48	14	11000
Example 54	ditto	1,4-diketo-2,5-diethyl-3,6-bis(1-naphthyl)pyrrolo[3,4-c]pyrrole	Compound [53]	611	ETM4	6.07	672	219	ditto	615	43	14	12000
Example 55	ditto	1,4-diketo-2,5-dimethyl-3,6-bis(1-naphtyl)pyrrolo[3,4-c]pyrrole	Compound [53]	613	ETM4	6.07	672	219	ditto	615	43	15	16000
Example 56	ditto	1,4-diketo-2,5-bis(4-methylbenzyl)-3,6-bis(4-p-tolylnaphthalene-1-yl)pyrrolo[3,4-c]pyrrole	Compound [53]	613	ETM4	6.07	672	219	ditto	616	43	13	9000
Example 57	ditto	1,4-diketo-2,5-dimethyl-3,6-bis(4-p-tolylnaphthalene-1-yl)pyrrolo[3,4-c]pyrrole	Compound [53]	613	ETM4	6.07	672	219	ditto	616	43	15	15000

Example 54

Synthesis of 1,4-diketo-2,5-diethyl-3,6-bis(1-naphthyl)pyrrolo[3,4-c]pyrrole

[0126] In 36 mL of t-amyl alcohol, 7.3 g of potassium-t-butoxide were dissolved, and then 10g of 1-naphthonitrile were added stirring the solution at 90°C. Into the solution, 6.7 mL of diisopropyl succinate were dropped over a period of 2 hours and were placed under reflux for one day. Next, 30 mL of methanol and 4.4 mL of acetic acid were added at 60°C and then refluxed for 30 minutes. After cooling, the product was separated out through a filter and subsequently rinsed with methanol, thus resulting in a red powder. Next, 2.89 g of the resulting red powder were dissolved in 80 mL of DMF, and 2.1 g of potassium-t-butoxide were added and stirred for one hour. Then, 1.5 mL of methyl iodide was added and stirred at 65°C for one day. After addition of 50 mL of water, extraction was performed with dichloromethane. The extract was concentrated and refined through a column chromatography with silica gel, thus resulting in 1.5 g of yellow powder. The following were the results of ^{1}H-NMR analysis.
^{1}H-NMR ($CDCl_3$ (δ = ppm)): 0.93(tt, 6H), 3.35(qq, 2H), 3.70(qq, 2H), 7.58-7.68(m, 6H), 7.76(t, 2H), 7.90(m, 4H), 8.02 (d, 2H)

[0127] Elemental analysis was performed on the assumption that the composition formula of the powder was $C_{30}H_{24}N_2O_2$. The results were as follows. Values in parentheses are theoretical values.
C: 81.2% (81.1%), H: 5.3% (5.4%), N: 6.3% (6.3%), O: 7.2% (7.2%)

[0128] According to mass spectrometry, the main molecular ion peak of the object powder was m/Z = 444. Thus, the resulting yellow powder was identified as 1,4-diketo-2,5-diethyl-3,6-bis(1-naphthyl)pyrrolo[3,4-c]pyrrole.

[0129] Subsequently, an LED was prepared using this 1,4-diketo-2,5-diethyl-3,6-bis(1-naphthyl)pyrrolo[3,4-c]pyrrole as a host material and the compound [53] as a dopant. Other process steps were the same as in Example 53. This resulting LED generated a red emission having an emission peak wavelength of 615 nm and a spectrum half band width of 43 nm provided by the compound [53]. The red emission exhibited a luminance of 12000 cd/m^2 under an applied voltage of 14 V.

Example 55

[0130] Using 1,4-diketo-2,5-dimethyl-3,6-bis(1-naphthyl)pyrrolo[3,4-c]pyrrole as a host material, an LED was prepared. Other process steps were the same as in Example 54. This resulting LED generated a red emission having an emission peak wavelength of 615 nm and a spectrum half band width of 43 nm provided by the compound [53]. The red emission exhibited a luminance of 16000 cd/m^2 under an applied voltage of 15 V.

Example 56

Synthesis of 1,4-diketo-2,5-bis(4-methylbenzyl)-3,6-bis(4-p-tolylnaphthalene-1-yl)pyrrolo[3,4-c]pyrrole

[0131] Instead of 1-naphthonitrile and methyl iodide, 4-p-tolyl-1-naphthonitrile and 4-methylbenzyl bromide were used, respectively. Other process steps were the same as in Example 54. Thus, 1.2 g of orange powder were obtained. The following were the results of ^{1}H-NMR analysis.
^{1}H-NMR ($CDCl_3$ (δ = ppm)): 2.20(s, 6H), 2.49(s, 6H), 4.38(t, 2H), 4.93(t, 2H), 6.69(t, 4H), 6.88(t, 4H), 7.35(d, 4H), 7.42-7.64(m, 12H), 8.00(t, 4H)

[0132] Elemental analysis was performed on the assumption that the composition formula of the powder was $C_{56}H_{44}N_2O_2$. The results were as follows. Values in parentheses are theoretical values.
C: 86.6% (86.6%), H: 5.7% (5.7%), N: 3.5% (3.6%), O: 4.1% (4.1%)

[0133] According to mass spectrometry, the main molecular ion peak of the object was m/Z = 776. Thus, the resulting orange powder was identified as 1,4-diketo-2,5-bis(4-methylbenzyl)-3,6-bis(4-p-tolylnaphthalene-1-yl)pyrrolo[3,4-c] pyrrole.

[0134] Subsequently, an LED was prepared using this 1,4-diketo-2,5-bis(4-methylbenzyl)-3,6-bis(4-p-tolylnaphthalene-1-yl)pyrrolo[3,4-c]pyrrole as a host material. Other processes were the same as in Example 54. This resulting LED generated a red emission having an emission peak wavelength of 616 nm and a spectrum half band width of 43 nm provided by the compound [53]. The red emission exhibited a luminance of 9000 cd/m^2 under an applied voltage of 13 V.

Example 57

Synthesis of 1,4-diketo-2,5-dimethyl-3,6-bis(4-p-tolylnaphthalene-1-yl)pyrrolo[3,4-c]pyrrole

[0135] Instead of 1-naphthonitrile and methyl iodide, 4-p-tolyl-1-naphthonitrile and methyl iodide were used, respectively. Other process steps were the same as in Example 54. Thus, 1.4 g of orange powder were obtained. The following were the results of ^{1}H-NMR analysis.
^{1}H-NMR ($CDCl_3$ (δ = ppm)): 2.49(s, 6H), 3.05(s, 6H), 7.35(d, 4H), 7.44-7.65(m, 10H), 7.98(d, 2H), 8.02(dd, 4H)

[0136] Elemental analysis was performed on the assumption that the composition formula of the powder was $C_{42}H_{32}N_2O_2$. The results were as follows. Values in parentheses are theoretical values.
C: 84.6% (84.6%), H: 5.4% (5.4%), N: 4.7% (4.7%), O: 5.3% (5.4%)

[0137] According to mass spectrometry, the main molecular ion peak of the object was m/Z = 596. Thus, the resulting orange powder was identified as 1,4-diketo-2,5-dimethyl-3,6-bis(4-p-tolylnaphthalene-1-yl)pyrrolo[3,4-c]pyrrole.

[0138] Subsequently, an LED was prepared using this 1,4-diketo-2,5-dimethyl-3,6-bis(4-p-tolylnaphthalene-1-yl)pyrrolo[3,4-c]pyrrole as a host material. Other process steps were the same as in Example 54. This resulting LED generated a red emission having an emission peak wavelength of 616 nm and a spectrum half band width of 43 nm provided by the compound [53]. The red emission exhibited a luminance of 15000 cd/m^2 under an applied voltage of 15 V.

Example 58

[0139] Using 1,4-diketo-2,5-dimethyl-3-(1-naphthyl)-6-(3,5-bis(1-naphthyl)phenyl)pyrrolo[3,4-c]pyrrole as a host material and the compound [1] as a dopant, an LED was prepared. Other process steps were the same as in Example 54. This resulting LED generated a red emission having an emission peak wavelength of 616 nm and a spectrum half band width of 48 nm provided by the compound [1]. The red emission exhibited a luminance of 9000 cd/m^2 under an applied voltage of 13 V.

Example 59

Synthesis of 1,4-diketo-2,5-bis(4-methylbenzyl)-3,6-bis(1-phenanthryl)pyrrolo[3,4-c]pyrrole

[0140] Instead of 1-naphthonitrile and methyl iodide, 1-phenanthrenecarbonitrile and 4-methylbenzyl bromide were used, respectively. Other process steps were the same as in Example 54. Thus, 0.9 g of orange powder were obtained. The following were the results of ^{1}H-NMR analysis.
^{1}H-NMR ($CDCl_3$ (δ = ppm)): 2.18(ss, 6H), 4.40(t, 2H), 4.90(t, 2H), 6.64(t, 4H), 6.79(t, 4H), 7.62-7.86(m, 12H), 7.96(t, 2H), 8.79(t, 4H)

[0141] Elemental analysis was performed on the assumption that the composition formula of the powder was $C_{50}H_{36}N_2O_2$. The results were as follows. Values in parentheses are theoretical values.
C: 86.3% (86.2%), H: 5.2% (5.2%), N: 3.9% (4.0%), O: 4.5% (4.6%)

[0142] According to mass spectrometry, the main molecular ion peak of the object was m/Z = 696. Thus, the resulting orange powder was identified as 1,4-diketo-2,5-bis(4-methylbenzyl)-3,6-bis(1-phenanthryl)pyrrolo[3,4-c]pyrrole.

[0143] Subsequently, an LED was prepared using this 1,4-diketo-2,5-bis(4-methylbenzyl)-3,6-bis(1-phenanthryl)pyrrolo[3,4-c]pyrrole as a host material. Other process steps were the same as in Example 54. This resulting LED generated a red emission having an emission peak wavelength of 616 nm and a spectrum half band width of 43 nm provided by the compound [53]. The red emission exhibited a luminance of 13000 cd/m^2 under an applied voltage of 15 V.

Example 60

[0144] Using 1,4-diketo-2,5-dimethyl-3,6-bis(1-phenanthryl) pyrrolo[3,4-c]pyrrole as a host material, an LED was prepared. Other process steps were the same as in Example 54. This resulting LED generated a red emission having an emission peak wavelength of 616 nm and a spectrum half band width of 43 nm provided by the compound [53]. The red emission exhibited a luminance of 17000 cd/m^2 under an applied voltage of 14 V.

Table 5

	Hole transporting layer	Emissive layer			Electron transporting layer				Cathode	Emission peak wavelength (nm)	Spectrum half band width (nm)	Applied voltage (V)	Luminance (cd/m^2)
		Host material	Dopant	Fluorescent peak wavelength in CH2Cl2nm)		Ionization potential (eV)	Molecular weight	Tg (°C)					
Example 58	4,4'-bis(N-(m-tclyl)-N-phenylamino)biphenyl	1,4-diketo-2,5-dimethyl-3-(1-naphthyl)-6-(3,5-bis(1-naphthyl)phenyl)pyrrolo[3,4-c]pyrrole	Compound [1]	613	ETM4	6.07	672	219	Li 0.5 nm Al 150 nm	616	48	13	9000
Example 59	ditto	1,4-diketo-2,5-bis(4-methylbenzyl)-3,6-bis(1-phenanthryl)pyrrolo[3,4-c]pyrrole	Compound [53]	613	ETM4	6.07	672	219	ditto	616	43	15	13000
Example 60	ditto	1,4-diketo-2,5-dimethyl-3,6-bis(1-phenanthryl) pyrrolo[3,4-c]pyrrole	Compound [53]	613	ETM4	6.07	672	219	ditto	616	43	14	17000

Example 61

[0145] Using tris(5,7-diphenyl-8-quinolinolato)aluminium (III) as a host material, an LED was prepared by the same procedure as in Example 1 other than the host material used. This resulting LED generated a red emission having an emission peak wavelength of 613 nm and a luminance efficiency of 3.2 cd/A.

Comparative Example 2

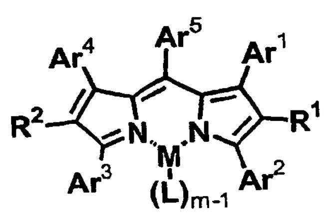
[0146] Using the compound [86] as the dopant, an LED was prepared by the same procedure as in Example 61 other than the dopant used. This resulting LED generated a red emission having an emission peak wavelength of 627 nm and a luminance efficiency of 1.0 cd/A.

Example 62

[0147] An ITO transparent conductive layer deposited on a glass substrate, having a thickness of 150 nm (produced by electron beam evaporation by Asahi Glass, 15 Ω/□), was cut into 30 mm × 40 mm and then was patterned with 32 stripes having a pitch of 300 μm (a width of the remaining ITO of 270 μm) by photolithography. The ITO stripes diverge up to a pitch of 1.27 mm (an opening width of 800 μm) in a longitudinal direction of the stripes in order to facilitate the electrical connection externally. The ITO plate was subjected to ultrasonic cleanings successively using acetone and cleaner Semicoclean 56 (produced by Furuuchi Chemical) for 15 minutes each, and then rinsed with ultrapure water. Subsequently, the ITO plate was subjected to ultrasonic cleaning in isopropyl alcohol for 15 minutes, then immersed in hot methanol for 15 minutes, followed by drying. The ITO plate was subjected to a UV-ozone treatment for one hour on the eve of the process of manufacturing an LED. Then, the ITO plate was placed in a vacuum vapor deposition apparatus and the apparatus was evacuated to a pressure of 5×10^{-4} Pa or below. On the ITO plate, a layer of TPD 100 nm in thickness was deposited. Next, 1,4-diketo-2,5-bis(3,5-dimethylbenzyl)-3,6-bis(4-ethylphenyl)pyrrolo[3,4-c] pyrrole as a host material and Compound [1] as a dopant were simultaneously deposited so as to form a layer having a thickness of 50 nm and a dopant content of 0.6 weight percent, and ETM2 was further deposited so as to have a thickness of 50 nm. Next, a mask which had been provided with 16 openings having a width of 250 μm (a remaining portion width of 50 μm and a pitch of 300 μm) on a Kovar plate by wet etching was fitting to the substrate, in vacuum, so that the openings of the mask orthogonally crossed the ITO stripes. The mask and the ITO plate adhesively came into contact with each other due to the presence of a magnet at the rear side. Then, a layer of magnesium 50 nm in thickness and a layer of aluminium 150 nm in thickness were disposed and thus a 32 × 16 dot matrix device was completed. By driving this device by a matrix system, characters could be displayed without cross talk.

Claims

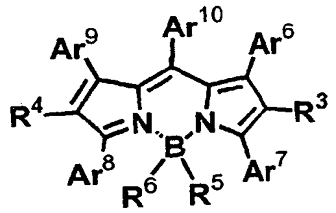
1. A pyrromethene metal complex represented by formula (1):



(1)

wherein each of R^1, R^2 and the or each L, independently of each other, is a group selected from hydrogen, alkyl, cycloalkyl, aralkyl, alkenyl, cycloalkenyl, alkynyl, hydroxyl, mercapto, alkoxy, alkylthio, aryl ether, aryl thioether, aryl, heterocyclic, halogen, haloalkane, haloalkene, haloalkyne, cyano, aldehyde, carbonyl, carboxyl, ester, carbamoyl, amino, nitro, silyl, siloxanyl, and fused aromatic and alicyclic rings each formed with an adjacent group selected from Ar^1 to Ar^4 and the or each group L and M is a metal having a valence of m and is selected from boron, beryllium, magnesium, chromium, iron, nickel, copper, zinc, and platinum; and each of Ar^1 to Ar^5, independently of each other, is an optionally substituted aryl group or any of Ar^1 to Ar^4, together with an adjacent group selected from R^1, R^2 and the or each group L may form a fused aromatic or alicyclic ring.

2. A pyrromethene metal complex represented by formula (2):



(2)

wherein each of R^3 to R^6, independently of each other, is a group selected from hydrogen, alkyl, cycloalkyl, aralkyl, alkenyl, cycloalkenyl, alkynyl, hydroxyl, mercapto, alkoxy, alkylthio, aryl ether, aryl thioether, aryl, heterocyclic, halogen, haloalkane, haloalkene, haloalkyne, cyano, aldehyde, carbonyl, carboxyl, ester, carbamoyl, amino, nitro, silyl, siloxanyl, and fused aromatic and alicyclic rings each formed with an adjacent group selected from R^3 to R^6 and Ar^6 to Ar^9; and each of Ar^6 to Ar^{10}, independently of each other, is an optionally substituted aryl group, or any of Ar^6 to Ar^9 together with an adjacent group selected from R^3 to R^6, may form a fused aromatic or alicyclic ring.

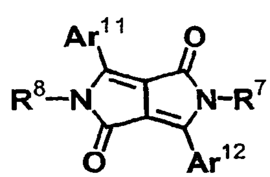
3. A pyrromethene metal complex according to Claim 1, wherein at least one of Ar^1 to Ar^4 is an aryl group substituted by an alkyl group having at least 4 carbon atoms.

4. A pyrromethene metal complex according to Claim 2, wherein both R^5 and R^6 are fluorine.

5. A light emitting device composition comprising a pyrromethene metal complex according to any preceding Claim.

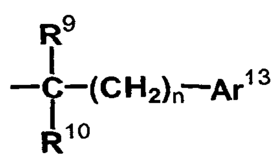
6. A light emitting device wherein a material which brings about light emission is present between an anode and a cathode, the light emitting device generates an emission having an emission peak wavelength in the range of 580 to 720 nm by electrical energy, and the material which brings about the light emission comprises at least one of:

(a) a diketopyrrolo[3,4-c]pyrrole derivative represented by formula (3) and an organic fluorescent material having a fluorescent peak wavelength in the range of 580 to 720 nm;
wherein formula (3) is:



(3)

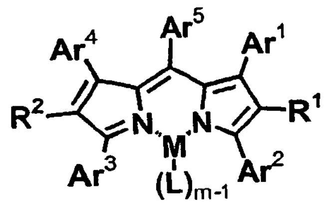
wherein R^7 and R^8 may be the same as or different from one another and each is a group selected from C_{1-25} alkyl groups and groups represented by formula (4):



(4)

wherein each of R^9 and R^{10}, independently of each other, is a group selected from hydrogen, C_{1-4} alkyl, phenyl having no substituent or substituted by C_{1-3} alkyl; Ar^{13} is selected from phenyl and naphthyl each substituted by alkyl, alkoxy, halogen or phenyl; and unsubstituted naphthyl; n is zero or a whole number of from 1 to 4; and each of Ar^{11} and Ar^{12}, independently of each other, is a group selected from phenyl, naphthyl, styryl and carbazolyl, and

(b) a light emitting device composition comprising a pyrromethene metal complex represented by formula (1), wherein formula (1) is:



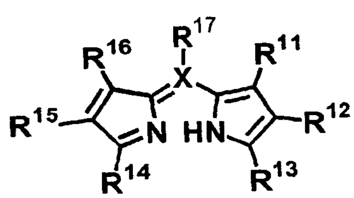
(1)

wherein each of R^1, R^2, and L, independently of each other, is a group selected from hydrogen, alkyl, cycloalkyl, aralkyl, alkenyl, cycloalkenyl, alkynyl, hydroxyl, mercapto, alkoxy, alkylthio, aryl ether, aryl thioether, aryl, heterocyclic, halogen, haloalkane, haloalkene, haloalkyne, cyano, aldehyde, carbonyl, carboxyl, ester, carbamoyl, amino, nitro, silyl, siloxanyl, and fused aromatic and alicyclic rings each formed with an adjacent group selected from Ar^1 to Ar^4 and the or each group L; M is a metal having a valence of m and is selected from boron, beryllium, magnesium, chromium, iron, nickel, copper, zinc, and platinum; and each of Ar^1 to Ar^5, independently of each other, is an optionally substituted aryl group or any of Ar^1 to Ar^4, together with an adjacent group selected from R^1, R^2 and the or each group L, may form a fused aromatic or alicyclic ring.

7. A light emitting device according to Claim 6, wherein the material which brings about the emission further comprises an emissive material and a hole transporting material and an electron transporting material, and the light emitting device composition comprises a diketopyrrolo[3,4-c]pyrrole derivative of the formula (3) and an organic fluorescent material.

8. A light emitting device according to Claim 7, wherein the diketopyrrolo[3,4-c]pyrrole derivative is a host material and the organic fluorescent material is a dopant.

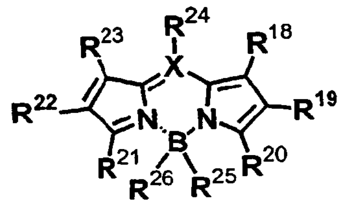
9. A light emitting device according to Claim 6, wherein the organic fluorescent material is a compound having a pyrromethene skeleton represented by formula (5)



(5)

wherein at least one of R^{11} to R^{17} is an optionally substituted aromatic ring or forms a fused ring with an adjacent group selected from R^{11} to R^{17}; each other of R^{11} to R^{17}, independently of each other, is a group selected from hydrogen, alkyl, cycloalkyl, aralkyl, alkenyl, cycloalkenyl, alkynyl, hydroxyl, mercapto, alkoxy, alkylthio, aryl ether, aryl thioether, aryl, heterocyclic, halogen, haloalkane, haloalkene, haloalkyne, cyano, aldehyde, carbonyl, carboxyl, ester, carbamoyl, amino, nitro, silyl, siloxanyl, and fused aromatic and alicyclic rings each formed with an adjacent group selected from R^{11} to R^{17}; X is carbon or nitrogen; and, when X is nitrogen, the group R^{17} is absent; or is a metal complex thereof comprising a metal selected from boron, beryllium, magnesium, chromium, iron, nickel, copper, zinc, and platinum.

10. A light emitting device according to Claim 9, wherein the metal complex is represented by formula (6):



(6)

wherein at least one of R^{18} to R^{24} is an optionally substituted aromatic ring or forms a fused ring with an adjacent group selected from R^{18} to R^{26}; each other of R^{18} to R^{24} and R^{25} and R^{26}, independently of each other, is a substituent selected from hydrogen, alkyl, cycloalkyl, aralkyl, alkenyl, cycloalkenyl, alkynyl, hydroxyl, mercapto, alkoxy, alkylthio, aryl ether, aryl thioether, aryl, heterocyclic, halogen, haloalkane, haloalkene, haloalkyne, cyano, aldehyde, carbonyl, carboxyl, ester, carbamoyl, amino, nitro, silyl, siloxanyl, and fused aromatic and alicyclic rings each formed with an adjacent group selected from R^{18} to R^{26}; and X is carbon or nitrogen, and, when X is nitrogen, the group R^{24} is absent.

11. A light emitting device according to Claim 6, wherein the organic fluorescent material comprises a pyrromethene metal complex represented by formula (1).

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Application Number
EP 02 25 2947

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